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ESTIMATING THE GREENHOUSE GAS BENEFITS OF FORESTRY PROJECTS: A Costa Rican Case Study

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Environmental Energy Technologies Division

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Abstract

If the Clean Development Mechanism proposed under the Kyoto Protocol is to serve as an effective means for combating global climate change, it will depend upon reliable estimates of greenhouse gas benefits. This paper sketches the theoretical basis for estimating the greenhouse gas benefits of forestry projects and suggests lessons learned based on a case study of Costa Rica's Protected Areas Project, which is a 500,000 hectare effort to reduce deforestation and enhance reforestation. The Protected Areas Project in many senses advances the state of the art for Clean Development Mechanism-type forestry projects, as does the third-party verification work of SGS International Certification Services on the project. Nonetheless, sensitivity analysis shows that carbon benefit estimates for the project vary widely based on the imputed deforestation rate in the baseline scenario, e.g. the deforestation rate expected if the project were not implemented. This, along with a newly available national dataset that confirms other research showing a slower rate of deforestation in Costa Rica, suggests that the use of the 1979-1992 forest cover data originally as the basis for estimating carbon savings should be reconsidered. When the newly available data is substituted, carbon savings amount to 8.9 Mt (million tones) of carbon, down from the original estimate of 15.7 Mt. The primary general conclusion is that project developers should give more attention to the forecasting land use and land cover change scenarios underlying estimates of greenhouse gas benefits.

Executive Summary

Purpose. If the Clean Development Mechanism proposed under the Kyoto Protocol is to serve as an effective means for combating global climate change, it will depend upon reliable estimates of greenhouse gas benefits. This paper sketches the theoretical basis for estimating the greenhouse gas (GHG) benefits of forestry projects and suggests lessons learned based on a case study of Costa Rica's Protected Areas Project. Estimating GHG benefits requires the construction of two scenarios of future land use, land cover change and associated GHG emission levels. These two scenarios are the baseline and project scenarios. A baseline is defined here as a hypothetical scenario of land use, land cover change and associated GHG emissions expected in the future if a proposed project were not implemented. A project scenario is a forecast of expected land use, land cover change and emissions levels anticipated should the project be implemented. While focusing on baseline scenarios, the paper also considers the analytical challenge of accounting for impacts indirectly caused by a project that have been broadly referred to as leakage.

Case Study—Protected Areas Project Description. The Costa Rican Office on Joint Implementation (OCIC) estimates that the Protected Areas Project (PAP), if fully funded and implemented, will result in approximately 15.7 million tonnes (Mt) of carbon savings over the 25-year life of the project. These carbon benefits are based on avoided deforestation and enhanced natural regeneration of secondary forestland. A linear extrapolation of past trends, disaggregated on a regional basis, is used to project baseline deforestation rates for the 27 protected areas included in the project. The OCIC designed a parallel project called the Private Forestry Project, to address concerns about negative leakage, e.g. displacement of deforestation pressure outside the project's boundaries. The Private Forestry Project is a program of environmental service payments to private landowners for a variety of land uses that increase forest cover: timber plantations, sustainable forest management, reforestation, natural regeneration and conservation of primary forest. These environmental service payments are meant to encourage private landowners outside of the protected areas to maintain or increase forest cover on their lands, thereby ensuring that the PAP does not lead to increased deforestation outside of protected areas.

Case Study Findings. In many ways, the PAP has advanced the methodological frontier for forestry projects. The project goes further than any other in developing rigorous and creative approaches to solving the technical challenge of accounting for the GHG impacts of forestry projects. Confidence in estimated carbon savings is bolstered by the OCIC's retention of SGS International Certification Services, Ltd. as a third-party evaluator. The PAP is one of only a few projects that have employed third party monitoring, evaluation, and certification. Substantial amounts of data about the project have been made available through SGS's reports. Such transparency should enhance the project's credibility, as well as facilitate the identification of possibilities for improvement in the evaluation of GHG impacts, thereby further increasing confidence in the project.

SGS's risk and uncertainty assessment methodology is a particularly useful contribution. SGS's assessment of risk and uncertainties associated with the 1.7 Mt of carbon offsets anticipated due to the consolidation of the first 30,000 hectares of land included in the project has led to the retention of 670,000 tonnes of carbon, almost 40% of the total carbon benefits in this first phase, in a buffer. The carbon offsets held in the buffer may not be sold unless further research demonstrates their validity.

The design of the baseline for the project serves to insulate the project from claims of exaggerated estimates of GHG benefits in three ways: (1) carbon pools other than trees are not included in the estimation of carbon savings; (2) GHG flows other than carbon dioxide are excluded, and; (3) selective logging, e.g. forest degradation as contrasted with deforestation[1], is not considered in the baseline, which means that the benefits of eliminating selective logging in the project scenario are ignored in the calculation of the project's overall benefits.

This report also identifies two technical weaknesses in the baseline that may undermine confidence in the PAP if not addressed. These weaknesses are (1) the time interval (1979-1992) used as the empirical basis for the OCIC's linear extrapolation of baseline deforestation rates—this time interval includes periods of rapid deforestation, yet there has been a marked slowdown in deforestation in Costa Rica since the mid-1980s, and; (2) the assumption of constant carbon content on secondary forest and pasture land in the baseline scenario lacks an empirical basis for the underlying reasoning that the countervailing forces of deforestation and biomass growth will cancel each other out.

To further illuminate recent deforestation trends, LBNL acquired and analyzed recently compiled national forest cover data for 1986 and 1997. This data was not available when the OCIC and SGS were doing their work. LBNL's analysis of the newly available data supports other evidence that Costa Rican deforestation has decreased significantly in recent years. The deforestation rates found by LBNL were used to explore the sensitivity of the carbon savings produced by the project. Carbon savings were found to vary widely with different assumptions about deforestation rates. Three scenarios (high, medium and low) were tested for comparison to the OCIC/SGS scenario, which is highlighted in gray in the table below.

[1] Deforestation is defined herein as complete long-term clearance of forest cover and conversion of land to a non-forest land use such as agriculture.

Sensitivity of Estimated Carbon Savings to Changes in Imputed Baseline Deforestation Rates

Scenario (Empirical Basis for Imputation of Baseline Deforestation Rates)	**Imputed Baseline Deforestation Rate**[1]	**Total Carbon Savings**
OCIC/SGS (1979-1992 deforestation rates in 10 km boundary zone outside protected areas)	0.849%	15.7 Mt
High Deforestation (1979-1986 deforestation rates in 10 km boundary zone outside of protected areas)	2.15%	29.9 Mt
Medium Deforestation (1986-1997 deforestation rates in 10 km boundary zone outside of protected areas)	0.376%	8.94 Mt
Low Deforestation (1986-1997 deforestation rates inside protected areas)	0.056%[2]	4.64 Mt

Sources: FONAFIFO (1998), SGS (1998).

[1] This rate was calculated by (1) applying the OCIC baseline methodology to the raw empirical data on deforestation rates listed in column one and (2) finding the average deforestation rate for the protected areas weighted according to area of primary forest.

[2] Note that this scenario departs from the OCIC approach of using deforestation rates observed in a 10km boundary zone surrounding protected areas as the basis for estimating baseline deforestation rates. Instead, this scenario assumes that baseline deforestation rates will equal deforestation rates observed inside protected areas over the last decade.

Given the slower rate of deforestation in Costa Rica since the mid-1980's and the sensitivity of carbon savings to the imputed baseline deforestation rates, the 1986-1997 data should be used to revise baseline deforestation rates for the project. SGS recommends development of a non-linear extrapolation model to enable more accurate imputation. This would be useful, but, for such a large project, even more sophisticated structural modeling would likely be justified.

While many mitigation projects have simply ignored the issue of leakage, the OCIC addresses it for the PAP by initiating a parallel effort, the Private Forestry Project (PFP), to counteract the potential for negative leakage. The aim of the PFP is to increase the amount of forest cover on land outside of the PAP's boundaries. This approach offers conceptual simplicity in so far as it avoids the difficult analytical issue of precisely quantifying the impact of leakage on overall project benefits. Furthermore, SGS recognizes that some leakage is still possible and recommends that some carbon offsets will have to be added to the buffer, although none of the offsets from the first Tranche were set aside to account for the chance of leakage for specific reasons discussed in the body of the text. The fact that the environmental service payments at the core of the PFP were suspended in July of 1998 is problematic. Moreover, the PFP does not penalize landowners for withdrawing from the program. The landowners only have to return whatever payments they received. Such an incentive structure cannot provide long-term guarantees. Changing economic circumstance could cause a non-forest land use to become more profitable than continuing to participate in the PFP, in which case some landowners would likely convert their land to those other uses.

Conclusion. The case study points to lessons for improving confidence in GHG emissions reduction estimates that fall into three categories:

(1) Ex-ante baseline construction. To date, projections of baseline land use change have been made with less analytic rigor than the estimation of the associated emissions levels, yet the former is a greater source of uncertainty than the latter. Project developers should give more attention to the prediction of baseline land use change.

(2) Ex-post baseline evaluation. The variability of deforestation rates over time highlights the need for effective monitoring and evaluation after implementation. While in the case of the PAP, no scientifically-valid control plots can be set aside as a basis for ex-post evaluation, national monitoring can indicate in a more general way the deforestation pressure to which the protected areas would have been subjected without the project. SGS's methodology offers a useful framework for incorporating judgements about uncertainty and for utilizing dynamic baselines. More work remains to be done on the methods and procedures needed to effectively implement dynamic baselines.

(3) Leakage. Indirect effects of projects must be considered to guard against overestimation of benefits. One approach, demonstrated by the PAP, is to design parallel activities meant to ensure that negative leakage does not occur.

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

AIJ	Activities Implemented Jointly
CDM	Clean Development Mechanism
CIEDES	Research Center for Sustainable Development (University of Costa Rica)
DSM	Demand-Side Management
FAO	Food and Agricultural Organization of the United Nations
FCCC	Framework Convention on Climate Change
FONAFIFO	National Forestry Fund of Costa Rica
GHG	Greenhouse Gas
IMN	National Geographic Institute of Costa Rica
LBNL	Lawrence Berkeley National Laboratory
Mt	Million Tonnes (Megaton)
NGO	Non-Government Organization
OCIC	Office on Joint Implementation of Costa Rican
PAP	Protected Areas Project
PFP	Private Forestry Project
TSC	Tropical Science Center
USIJI	United States Initiative on Joint Implementation
WRI	World Resources Institute

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INTRODUCTION

1. The Concept of a Baseline and Overview of the Paper

1.1. The Definition and Purpose of a Baseline

The scientific, technical, and policy analyses underlying negotiations and decision-making about global climate change depend upon predictions of how emissions of greenhouse gases (GHGs) would grow in the future without mitigation activities. Such a hypothetical description of GHG emissions over a period of time without mitigation activities is called a baseline. A baseline is also sometimes referred to as a reference case, without project scenario, or business-as-usual scenario.

Depending upon the proposed mitigation activity being studied, baselines can be specific to a project or sector or they can be national in scope. Countries that made commitments to reduce GHG emission as part of the Kyoto Protocol, known as Annex B countries (developed countries), each have developed national baseline scenarios against which their commitments can be measured. The Kyoto Protocol also authorizes Annex B countries to receive emission reduction credit for investment in climate change mitigation projects outside of their borders. Such projects are to be referred to as Jointly Implementation projects if they take place in an Annex B country and as Clean Development Mechanism projects if they are located in a non-Annex B (developing) country. A project specific baseline can serve as the basis for estimating GHG benefits due to Joint Implementation or Clean Development Mechanism projects. GHG benefits will equal the difference between emissions in the baseline, e.g. without project, and project scenarios.

To project baseline GHG emissions, first it is necessary to anticipate changes in human activity that would have occurred without the project and their impacts on future emissions. Thus, for a project promoting energy-efficient light bulbs, developing a baseline requires prediction of future developments in the light bulb market and patterns of light bulb usage. The analyst must anticipate consumption and usage of conventional light bulbs as well as the possibility that some energy-efficient light bulbs would have been utilized without the project. The energy savings of the project scenario compared to the baseline scenario will determine the emissions reductions due to the project. For a forest protection project, construction of a baseline requires a forecast of how the forestland would have been impacted by human activities otherwise. Once the extent of future deforestation without the project has been imputed, GHG impacts can be estimated.

The hypothetical nature of baseline creates perplexing analytical difficulties. Once project implementation has begun, what would have happened without the project is purely conjectural. Empirical analysis cannot prove conclusively whether or not a baseline is accurate. There are methods for ex-post analysis of project baselines that are useful for assessing baseline accuracy (discussed in section 3.5.). Yet, none can guarantee precision.

This analytical problem is compounded by the fact that in a market for GHG offsets, buyers and sellers both have incentives to establish baselines that exaggerate the GHG offsets due to mitigation projects (Michaelowa 1998; Goldemberg 1998). Sellers will receive more revenue and buyers may face lower prices if more GHG offsets are available. Overstated baselines would lead to increased GHG emissions for the globe. If credit for GHG offsets exceeds actual reductions, Annex 1 countries may be able to claim that they have satisfied their emission reduction commitments while in fact having exceeded them. Baselines that exaggerate GHG benefits will also divert investment away from worthy projects with more accurate baselines (Chomitz 1998). The possibility that baseline inaccuracy will lead to higher GHG emissions is one of the concerns commonly raised about jointly implemented projects (Sathaye et al. 1998).

1.2. Objective of the Paper

This paper undertakes a case study of Costa Rica's Protected Areas Project with the objective of informing discussions about the reliability of estimates of the greenhouse gas (GHG) benefits due to forestry project. The paper starts by describing the theory and practice of baseline construction and especially the challenge of imputing, e.g. predicting or projecting, baseline deforestation rates. To date, developers of forest projects have focused with greater analytic rigor on the estimation of GHG flows, e.g. the carbon content of different types of forestland, than on imputation of baseline deforestation rates. The issue of the indirect effects of projects, frequently referred to as leakage, is also examined. Approaches are suggested for enhancing the credibility of baselines and assessments of the risk of leakage.

1.3. Organization of the Paper

Part One of the paper, which follows this Introduction, outlines the theory and practice of constructing baselines for forestry projects and describes the concept of leakage (indirect project effects). Part Two examines in detail Costa Rica's Protected Areas Project. The Conclusion summarizes the case study findings and suggests lessons for ex-ante and ex-post GHG accounting.

Part One is comprised of five sections. Section 2 describes the potential for climate change mitigation activities in the forestry sector. Section 3 discusses the technical elements of a baseline, while Section 4 covers aspects of baseline construction specific to forestry projects. Section 5 introduces the concept of indirect project impacts. Criteria for evaluating baselines are suggested in Section 6.

Part Two, the case study, consists of six sections. Section 7 provides an overview of Costa Rica's Protected Areas Project. Section 8 summarizes the literature on Costa Rican deforestation with an emphasis on rates and dynamics of deforestation. Section 9 reports LBNL's original analysis of a recently compiled data set on forest cover for 1986-1997, which was undertaken with the goal of further illuminating recent deforestation trends. Section 10 describes the PAP's baseline in further detail and offers an assessment of the baseline and the project's approach to leakage. Section 11 demonstrates the sensitivity of estimates of carbon savings to changes in baseline deforestation rates. Section 12 reviews the work done by SGS International Certification Services, a firm that was hired by the Costa Rican authorities to provide third-party evaluation of the project.

PART ONE: THE THEORY AND PRACTICE OF CONSTRUCTING BASELINES FOR FORESTRY PROJECTS

2. Climate Change and the Forestry Sector

Deforestation[2] has played a major role in the accumulation in the atmosphere of carbon dioxide, the most important GHG in terms of impact on climate. One study estimates that 30 percent of carbon dioxide accumulated in the atmosphere is attributable to human-caused deforestation (Austin et al. in press). Another study found that more than 20% of current carbon dioxide emissions are due to change in land use and land cover (SGS 1998). Moreover, the Intergovernmental Panel on Climate Change (IPCC) predicts large emissions of carbon dioxide due future deforestation unless mitigation efforts are undertaken. The IPCC (1996) estimates that mitigation projects in the forestry sector could conserve between 60 and 87 billion tonnes of carbon by 2050.

2.1. Mitigation Options in the Forestry Sector[3]

Forestry management practices that will reduce the growing concentration of carbon dioxide in the atmosphere can be separated into three categories: (1) conservation; (2) sequestration and storage, and; (3) carbon substitution. Conservation practices decrease the emission of carbon from existing forests. The slowing of deforestation is an important example. Other conservation options include the adoption of less-destructive harvesting regimes and controlling outbreaks of fire and pests. Sequestration and storage practices increase the area of land covered by forests or increase the carbon density of natural and plantation forests. Carbon substitution seeks to replace fossil fuel-intensive energy and products (such as cement and steel) with forest biomass energy and products that can store forest biomass carbon.

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[2] Deforestation is defined herein as complete long-term clearance of forest cover and conversion of land to a non-forest land use such as agriculture.

[3] This section is based on the IPCC's SAR II, Chapter 24, *Management of Forests for Mitigation of Greenhouse Gas Emissions* (Lead Authors: S. Brown, J. Sathaye, M. Cannell, and P. Kauppi).

2.2. Evolution of the CDM and Debate over Forestry's Role

The United Nations Framework Convention on Climate Change (FCCC) briefly mentioned the possibility of bilateral or multilateral cooperation to mitigate global climate change (Article 4.2. (a) & (b) of FCCC 1992). The idea of one nation investing in mitigation activities outside of its borders in cooperation with another nation became known as joint implementation. At the first Conference of Parties to the FCCC in Berlin, a pilot phase was initiated to test the concept of joint implementation (Decision 5/CP.1 of FCCC/CP/1995/7/Add.1). Projects initiated during this pilot phase are called Activities Implemented Jointly (AIJ) projects. The guidelines adopted at Berlin indicate that countries participating in AIJ projects will not receive emission reduction credit during the pilot phase, although the possibility exists that credit could be awarded retroactively.

The Kyoto Protocol to the FCCC, agreed at the third Conference of Parties in 1997, further developed the idea of joint implementation. A more general phrase— flexibility mechanisms— has emerged to refer to the idea of one country investing in GHG emission reduction projects in another country (Panayotou 1998). The Kyoto Protocol distinguishes four types of flexibility mechanisms: (1) Bubbles; (2) Joint Implementation; (3) Emissions Trading, and; (4) the Clean Development Mechanism. *Bubbles* allow groups of countries to cooperatively address their emission reduction commitments by trading among themselves if they agreed to do so at Kyoto. The European Community is an example of such a bubble. *Joint Implementation* allows Annex B countries to acquire emission reduction units for investment in mitigation projects located in other Annex B countries in order to supplement domestic actions. *Emissions Trading* allows Annex B countries that reduce emissions below their commitment level to sell their excess emission reduction units. The *Clean Development Mechanism* (CDM) gives Annex B countries the option of investing in emissions reduction projects in non-Annex B countries to contribute to their compliance with emissions commitments and to promote sustainable development in non-Annex B countries.

Many details of the CDM's operational character remain undetermined. Article 12, which defines the CDM, was only adopted during the last hours of the meeting at Kyoto (Goldemberg 1998). The question of whether or not forestry projects will be allowed under CDM continues to be debated. The language in Article 12 neither explicitly includes nor excludes such land use projects. A work program to further develop the CDM and other flexibility mechanisms was agreed to at the fourth Conference of Parties held in Buenos Aires with decisions on the modalities of the CDM and how sinks will be handled by the Kyoto Protocol expected at the sixth or seventh Conference of Parties in late 2000 or 2001. At Buenos Aires it was also agreed that the AIJ pilot phase will continue and should be reviewed by the end of the year 2000 (Trexler 1998).

3. Elements of a Baseline

3.1. Additionality

A project is additional if it causes reductions in GHG emissions that would not have been realized without the project. Additionality is a unique and basic requirement for AIJ or CDM projects. Additionality is not an issue in mitigation activities occurring within Annex B countries. The emissions limitations and reductions accepted by Annex B countries at Kyoto are to be measured against 1990 emissions levels. Non-Annex B countries have not established national baselines. Thus, projects aiming to reduce GHG emissions must be judged on a project-by-project basis in non-Annex B countries.

Additionality and baselines are inextricably linked. Both assessment of additionality and baseline construction start with the same question: what would have happened in the future without the project? Developing a credible baseline that shows emissions reductions is one of the methods that has been suggested for demonstrating additionality. Different ways of judging additionality have also been proposed. It has been suggested that categories of projects could be established which would be considered a priori additional. For example, all geothermal energy generation projects might be considered additional. This categorical means of judging additionality is related to the still nascent benchmarking approach to baselines, which is discussed in Section 3.2. Alternatively, additionality could be based on a determination of whether or not the project will overcome institutional, capital, or other market barriers that would have otherwise prevented its implementation (Yamin 1998).

Panayotou (1998) suggests that additionality can be thought of generally in two ways, weak and strong additionality. Weak additionality implies that a project would lead to emissions reductions that go beyond the minimum legal or regulatory requirements of a host country. Strong additionality applies if a project decreases emissions compared to a credible baseline scenario.

Analysis of additionality usually considers two different aspects: emissions and financial additionality. Emissions, or environmental, additionality refers to the need for projects to actually change the course of the host country's development such that GHG emissions are reduced. Financial additionality requires that investment in a project should not divert Global Environmental Facility funding or bilateral development assistance (Andrasko et al. 1996). Financial additionality might also be interpreted as indicating that projects that produce net benefits must demonstrate the reasons (e.g. barriers) that prevent the realization of these gains, which would be in the self-interest of the host country.[4]

Two clauses in the guidelines for AIJ indicate the basis for emissions and financial additionality requirements. They state that: "[AIJ] should bring about real, measurable, long-term environmental benefits related to the mitigation of climate change that wold not have occurred in the absence of the project… [and]… the financing of [AIJ] shall be additional to the financial obligations of Parties included in Annex II to the Convention within the framework of the financial mechanism as well as to current official development assistance," (Decision 5/CP.1 of FCCC/CP/1995/7/Add.1).

The Kyoto Protocol uses similar words to describe the additionality requirement for CDM project, but there is no explicit reference to financial additionality. Emissions reduction credits due to CDM projects must have: "Real, measurable, and long-term benefits related to the mitigation of climate change; and Reductions in emissions that are additional to any that would occur in the absence of the certified project activity," (Article 12 (b) & (c) of FCCC/CP/1997/L.7/Add.1).

3.2. Types of Baselines: Project Specific, Benchmark, Sectoral

This paper focuses on the task of baseline construction for CDM projects. To date, all AIJ projects have utilized project specific baselines. However, two alternatives to project specific baselines have been identified. These are (1) benchmarking and (2) sectoral baselines, which are in effect national baselines for a sector such as energy, transport, or agriculture.

A benchmark is a pre-determined measure (of carbon intensity for energy and industrial activities or deforestation rates for land use change) that can be used to assess additionality and emission reduction benefits due to a CDM project (Tellus Institute 1999). Once a benchmark has been set for a particular kind of project, all projects within a country, or possibly a region, are then judged against that baseline. The specific location of the project is not relevant. This avoids the problem of predicting what exactly would have happened in a particular place. Further, the size of the project is only relevant in estimating the emission reductions due to the project, not in determining the baseline.

Consider an example for the steel industry. A benchmark for steel production could be some standard measure such as kilograms of carbon dioxide per kWh of energy used or tons of carbon dioxide per ton of steel. The carbon savings for a project would be calculated by multiplying the projected output of the steel plant by the difference between the benchmark carbon intensity and the CDM project's anticipated carbon intensity (ibid.).

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[4] For example, a carbon dioxide recovery AIJ project at a brewery in Zagreb, Croatia projects annual gains of $250,000 annually for the business. See http://www.unfccc.de/fccc/ccinfo/aijproj.htm.

Benchmarks could be defined in three ways: (1) historical levels; (2) extrapolation or structural modeling, and; (3) normative judgements. A historical mean or median value could be assumed to hold as a constant in the future. An extrapolation of past trends or structural modeling could be used to project future carbon intensities or deforestation rates. Extrapolation and structural modeling are discussed further in Section 3.4., methods for ex-ante projection. Finally, benchmarks could be set on a normative basis, which means some judgement could be made with respect to the expected future level of energy efficiency or forest projection without the project.

Sectoral caps create a GHG emissions limit for a sector, such as forestry or electricity generation. Projects that reduce emissions below the cap create GHG offsets. There are advantages to the approach, but it raises new analytic questions and political difficulties (Chomitz 1998). Sectoral baselines could reduce the transaction costs associated with baseline construction. Only one sectoral baseline, rather than many small, area and project specific baselines, would be needed. The cost of sophisticated modeling to set a sectoral baseline would be smaller in relation to the offsets produced than for project specific baselines. Sectoral caps could also help guard against leakage, as long as a national baseline has been set to guard against leakage from one sector to another. Such a comprehensive view, as opposed to a narrow project specific perspective, makes it easier to account for all project impacts.

Sectoral caps raise new analytic and political challenges (ibid.). One question is how to allocate the emissions rights allowed under the cap, which will determine opportunities to produce offsets. The simplest solution would be to define emissions rights based on historical levels. On a political level, most non-Annex I, e.g. developing, countries are reluctant to establish national baselines.

3.3. Static vs. Dynamic Baselines

A static baseline is one that does not change once project implementation and operation has begun. A dynamic baseline allows for adjustment of the ex-ante baseline after project implementation has begun. The ex-post adjustment could be a one-time event or could occur on a periodic basis.

The hypothetical nature of baselines means that after a project has been implemented, it is impossible to tell exactly what would have happened otherwise. Nonetheless, ex-post analysis can provide useful insight. For example, suppose the ex-ante baseline for a fuel-switching project assumed that the price of coal would be lower in the future than it turns out to be. In this case, a static baseline would underestimate the carbon offsets the project has produced. Similarly, suppose a forest conservation project assumes a higher rate of deforestation than ex-post analysis suggests would have occurred. Here, a static baseline would overstate the amount of carbon offsets generated.

Dynamic baselines increase analytical complexity and cost to some extent. However, dynamic baselines need not be as costly as they seem upon first reflection. The emissions reductions claimed by AIJ/CDM projects will be subject to some form of regular monitoring, evaluation, and certification (Vine and Sathaye 1997). These mandatory activities mean that the calculation of dynamic baselines need not require substantial additional data collection or analysis. What's more, dynamic baselines need not increase the risk to investors (Chomitz 1998). Static baselines do not ensure that ex-ante prediction of emissions reduction will be realized. Assuming that monitoring, evaluation, and certification are carried out, static and dynamic baselines will have the same result for investors who participate in projects that fail to produce real, measurable emissions reductions. In the case of the static baseline, some portion of the emissions reduction will not be certified. In the case of a dynamic baseline, the estimation of net emissions benefits will be adjusted to reflect the outcome of the ex-post evaluation. Such adjustments could be based on variables such as load factors or fuel prices for energy projects and deforestation rates or timber prices for forestry projects (Chomitz 1998).

SGS (Société Générale de Surveillance) International Certification Services Ltd. has developed an approach to dynamic baselines that at the same time addresses questions of uncertainty and risk (SGS 1998). In simplest terms, the SGS approach works this way. SGS estimates the quantity of carbon offsets a project is expected to produce. Next, SGS conducts a risk and uncertainty assessment, which is the basis for determining what fraction of the best estimate of carbon offsets should be held in a buffer, e.g. separated from the certified offsets and held in reserve. SGS will adjust the size of the buffer over time. SGS's certification service indicates corrective actions that project developers should undertake to improve the accuracy and certainty of estimated emissions reductions. SGS refers to this as a "continuous improvement" approach. SGS's approach to certification and its work on Costa Rica's Protected Areas Project will be examined in further detail as part of the case study.

3.4. Methods for Prediction

To establish an ex-ante, e.g. pre-implementation, baseline for a specific project, it is necessary to choose a method for predicting future emissions without the project. A tradeoff between cost and precision typically underlies the choice of method. Models that employ a more detailed representation of reality are more likely to be accurate, but are more costly as well. Many possible approaches can be imagined. Section 4 will discuss methods for modeling deforestation in more detail, but two broad categories of methods—extrapolation and structural modeling—are described here (Michaelowa 1998; Chomitz 1998):

1) *Extrapolation*. Past trends can be extrapolated into the future. The extrapolation could be linear or some other shape curve if there is an empirical or theoretical basis to believe the trend will be other than linear. The extrapolation, or time series, approach to modeling is particularly appropriate if the underlying causes driving the process of interest are substantially unknown. This can also be a relatively low cost method, but will be fairly accurate if past trends remain substantially unchanged. One possibility for making an extrapolation more accurate is to scale the prediction based on driving forces such population or economic growth. This would move extrapolation one step closer to the next method.

2) *Structural Modeling*. A wide range of methods exists for modeling the systems and processes that affect technological change and deforestation. Such methods are more costly, but are likely to be more accurate. Underlying forces can be represented, and if the dynamics of the system being represented do not change and if assumptions about changes in exogenous variables are appropriate, then predictions about the impact of a project may be very accurate.

3.5. Methods for Ex-Post Evaluation of Baselines

Ex-post evaluation of the baseline must be distinguished from monitoring and evaluation of developments in the field. Monitoring and evaluation of projects will provide an understanding of what is happening on the ground. Is a tract of forest that is supposed to be protected still fully intact? Is an energy-efficient light bulb being purchased and used as planned? These questions are separate from the question of whether the ex-ante *baseline* is accurate. They address the accuracy of the ex-ante *project* scenario.

Ex-post evaluation of the baseline is a more difficult endeavor. Rather than trying to judge what is happening on the ground, the analyst must assess what would have happened without the project. In the forestry case, if the tract of forest is still standing, how much would have otherwise been deforested? Returning to the energy-efficient light bulb example: How many of those purchasing a subsidized efficient bulb would have done so anyway (referred to in the literature as the free rider problem)? How many people bought energy efficient light bulbs that were not subsidized because of the project (the question of spillover)?

While ex-post baseline evaluation is inherently an imprecise endeavor because the baseline cannot be observed once the project has been implemented, it can still improve the accuracy of estimated project benefits. Three basic methods can be utilized to address the question of what would have happened in the absence of the project (Chomitz 1998):

1. *Surveys.* Project participants can be directly questioned about what they would have done in the absence of the project's implementation.

2. *Control Groups.* Groups of people or plots of land not involved in the project can be observed to assess what would have happened without the project.
3. *Ex-Post Adjustment of Predictive Models.* The exogenous variables that were used as inputs into models used to predict the baseline can be adjusted using the values observed.

Each of these methods has strengths and weaknesses. Surveys to determine free ridership rates depend upon the honesty of respondents, who may give the answer they perceive as "correct" or have other reason to answer strategically. Control groups offer the best opportunity for baseline evaluation. Chomitz (1998) calls them the "gold standard" for baseline validation. Nonetheless, finding valid control groups is a challenge. Usually some important difference exists between the project and control groups. Predictive models used to simulate the baseline scenario can be updated using actual values for exogenous variables. Nonetheless, if the model misrepresents basic relationships or processes, more accurate inputs will not produce accurate outputs.

3.6. Risk and Uncertainty

Global climate change projects and the emissions reductions they seek to produce are subject to a multitude of risks and uncertainties. Risk is present when a variety of outcomes are possible, and the probability of the different outcomes is known. Uncertainty occurs when various events may occur, and there is little basis for knowing how the future will unfold (Munasinghe 1993). Unlike risk, uncertainty can not be characterized with an empirically based probability distribution. Risk is sometimes called "quantifiable uncertainty," (Brant 1998).

The distinction between risk and uncertainty is not an absolute one. The confidence with which a probability distribution can be assigned to various possible outcomes will vary across a spectrum from no confidence to absolute confidence (such as the probability associated that a coin toss will fall as heads). Nonetheless, in baseline and project scenario construction it is useful for analysts to consider exactly how confident they are about their predictions. In certain areas, such as modeling and predicting deforestation, substantial restraint and modesty should be recognized. In other areas, such as calculating biomass and carbon content, greater certainty is reasonably anticipated.

SGS's approach to risk and uncertainty has been briefly mentioned and will be more fully discussed in Section 12.4, which discusses SGS's August 1998 assessment of the PAP. SGS's risk and uncertainty quantification mechanism is a valuable contribution to the problem of predicting future emissions reductions. It recognizes that risk and uncertainty are inevitable, but need not be paralyzing. The SGS approach also offers a framework for working to increase confidence in carbon offsets. At the same time, a certain degree of modesty is required when uncertainty quantification relies upon expert judgement as opposed to scientific studies. In other words, the buffer of carbon offsets that is created to ensure the validity of certified offsets must be large enough to credibly create a large enough confidence interval if 98% confidence is to be claimed.

Michaelowa (1998) suggests another method for incorporating analysis of uncertainty in baseline construction. He observes that one approach would be to develop a *mean baseline* derived from a set of baseline scenarios that each rely upon different, but plausible, assumptions. Different probabilities could be assigned to each of the baseline scenarios. The mean baseline would be a composite of the various potential future that have been envisioned that would weight each of the baselines according to its probability. Notably, this approach does not escape the need for important judgements (e.g. probabilities of scenarios) that will be based mainly on expert opinion rather than empirical data.

4. Constructing Baselines in Forestry

Baselines, be they for forestry or energy projects, can be decomposed into two elements. First, the behavioral or structural component must be predicted with some specified degree of precision. Future patterns of land cover and land use or technological change and energy consumption must be forecast. Then the GHG impacts of the behavioral prediction, e.g. the associated carbon flows, must be calculated.

4.1. Estimating Carbon Flows

The IPCC (1996) has concluded that uncertainty associated with carbon conservation and sequestration results mainly from high uncertainty about future patterns of deforestation, forestation and regeneration rather than uncertainty about measurements of carbon content. Research conducted in the 1990's substantially improved scientific understanding of carbon content and biomass growth rates of different ecosystem types. The IPCC reports with a high degree of confidence[5] that, "estimates of the net amount of C per unit area conserved or sequestered under a particular management scheme are relatively more certain [than underlying predictions of changes in land cover and land use]," (1996, p.775). The difficulty of predicting social, demographic, economic, and political developments over time is the greatest analytical challenge in estimating emission reductions in forestry. Substantial uncertainty continues to exist with respect to the carbon content of soils, but most AIJ projects have not included soils in their emissions reduction estimates (Brown et al. 1998). Readers are directed to *Estimating Biomass and Biomass Change of Tropical Forests* (Brown 1997) for further discussion of methods for analysis of carbon flows.

4.2. Methods for Modeling Deforestation

To construct a baseline, it is necessary to predict where and when deforestation would have occurred in the future without the project. Methods useful for predictive modeling of deforestation can be broadly described as mathematical representations where deforestation is a function of some other variables. Modeling methods differ in terms of their predictive approach, functional form, complexity, formulation of the dependent variable, independent variables included, scale, spatial specificity, temporal character and methodology used to characterize the functional relationship between the dependent and independent variables. These will be discussed and then summarized in Table 1 below.

[5] High confidence indicates virtual consensus among authors based on substantial empirical evidence.

One important distinction is a model's predictive approach. Is it an extrapolation of past trends or a structural representation of processes at work? The simplest method for predicting deforestation rates is extrapolation, which can be linear or non-linear.[6] A future trend is predicted based on past trends. Alternatively, a structural model can be developed that represents one or more of the processes underlying deforestation. These processes may be behavioral or physical in nature. A typical behavioral approach seeks to represent a landowners' decision-making process assuming that the objective is to maximize the value of the land. The process of changing soil fertility and land productivity over time on newly deforested land is an example of a physical process that might serve as a component of a structural model.

Chomitz recommends a behavioral modeling approach: "A powerful methodology for building such a model is to assume that the actors maximizing profits, subject to some constraints: "should have" as a mean to forecasting "would have," (Chomitz 1998). In their review of economic models of deforestation, Kaimowitz and Angelsen (1998) focus on such behavioral models, which they describe as economic models, or, "models that describe how landholders behave and why, and the linkages between their decisions and the rest of the economy," (ibid., 1). While such models have much to offer, it should also be noted that in some cases land use clearing decisions are not based on profit maximizing behavior. Rather land tenure, posterity, power, or security may be the objectives driving the behavior.

A broad range of functional forms and levels of complexity exists among deforestation models. They may be single equations or systems of equations. Systems can be simultaneously or recursively determined or hierarchically-ordered (e.g. a single equation comprised of variables that are in turn based on a subsystem equation). For complicated

[6] An even simpler method is possible. Future deforestation rates could be set at constant historical levels (e.g. at the level in one moment in time or averaged over a period of time). Such a constant baseline is not appropriate in most cases. The exception is when predictions must be made for small areas where land use activities have been stable over time.

models with multi-level equations, a variety of functional forms may be represented in a single model (e.g. regression, Markov chain, correlation, logistic, quadratic, and etc.).

Both Kaimowitz and Angelsen (1998) and Lambin (1994) identify three approaches to characterizing the functional relationship between deforestation, the dependent variable, and the independent variables included in a model. The three methodological approaches are called empirical, analytical (or mechanistic), and system (or simulation). Empirical models seek to capture the key dynamic relationships that affect deforestation. Regression analysis is an important example. Analytical models are more theoretical constructs, based on scientific theories about how processes (like ecosystems or machines) work. They may include parameters based on empirical data, and are subject to ex-post evaluation. Systems models draw on both empirical and analytic methods to create overlapping systems and subsystems. Positive and negative feedback among sub-systems can be represented. These models are typically more complicated (note greater complication is not synonymous with greater accuracy).

The definition of the dependent variable can differ among models. Most dependent variables will be defined as some form of deforestation, such as area of forest cleared per year or percentage of forest cleared per year. The expansion of agricultural land is also sometimes used as a dependent variable for in some cases agricultural expansion equals deforestation.

Models also vary according to causes of deforestation that they try to capture, indicated by the independent variables included. The scale of a model is also important as the various causes of deforestation operate at different levels of aggregation (Lambin 1994). Kaimowitz and Angelsen (1998) distinguish three scales of models: household and firm level, regional level, and national level. The appropriate scale will depend upon the key driving forces in a particular area. At the macro level, factors such as external debt and economic and forestry policy are important drivers. At the micro level, variables such as prices, wages, accessibility and risk will influence the decisions of potential agents of deforestation.

The general treatment of methods for ex-ante modeling in Section 3.4. discussed the common tradeoff between cost and accuracy of methods. The strengths and weaknesses of methods for modeling deforestation will be further addressed in the Appendix, which surveys methods for modeling deforestation and also discusses the causes of deforestation.

Table 1. Elements of Deforestation Models

Element	Description
Predictive approach	Trend projection; structural representation (behavioral or physical)
Functional form	Regression, Markov chain, correlation, logistic, quadratic etc.
Complexity	Ranges from single equation to multi-equation layered models
Methodology	Empirical, analytic, system
Definition of dependent variable	Typically area or rate of deforestation per year
Independent variables included	Depending upon relevant causes of deforestation in the study area, different independent variables are included. Examples include rural wages, proximity to roads, soil quality, slope of land, and etc.
Scale	Household or firm; regional; national
Time	Static or dynamic

5. Direct and Other Impacts

Once a baseline scenario has been developed, emissions that will occur if the project is implemented must be projected. This is the project scenario, also referred to as the with-project or mitigation scenario. A key challenge is the analysis of indirect effects of the projects that follow from the direct impacts. In developing a project scenario, and in monitoring and evaluating the project's performance after it is implemented, analytic boundaries should be established that capture not only direct impacts but the most substantial indirect impacts as well. This is called establishment of a monitoring domain (Andrasko 1997).

Indirect impacts have been categorized in various ways. Initially, they were broadly referred to as leakage. Indirect impacts can also be divided into three categories (Vine et al. 1999): leakage, spillover, and market transformation. Leakage is defined as a negative indirect impact. Spillover is defined as a positive indirect impact. Market transformation is a permanent change in consumer preferences and market structure that last after a project has ended.

The chief technical concern is leakage in which case indirect impacts would lead to smaller reductions in net emissions than have been estimated (Sathaye et al. 1998). For example, in the case of energy efficiency projects, there is the potential for a "snapback" effect (Vine and Sathaye 1998). Consider an example where energy savings due to the project save consumers money. In turn, some of this increased disposable income may be used to consume more fossil fuel based energy or to purchase products that consume more energy, thus increasing GHG emissions. The project may still affect a net decrease in emissions, but the gain will be smaller than predicted when looking only at direct impacts. On a macroeconomic level, energy efficiency measures may translate into lower demand for fossil fuels, which may lower prices, thus giving consumers an incentive to consume more than they would otherwise.

In the case of forestry, projects that reduce deforestation or increase the land area devoted to forest may simply displace the effects of the underlying driving forces, thus causing deforestation in areas that would otherwise be unaffected (Vine et al. 1999). Suppose an area of forest is in danger of being cleared and converted to agricultural use. Fencing the area off may protect that parcel of forest, but it does not change the underlying demand for food, which in turn creates a demand for agricultural land. The project may simply increase the likelihood that other forests will be converted to cropland or pasture.

It is difficult to quantify leakage and spillover impacts in an analytically rigorous way. The requisite data and computer intensive modeling approaches are expensive and time consuming. The field of impact assessment is confronting the same problem of predictive analysis of cumulative—direct and indirect—impacts (Canter 1997). At the national or sectoral level, the cost of complex modeling to judge the cumulative impacts of future changes is less prohibitive than for project specific baseline and mitigation scenarios. To date, no AIJ projects have established baseline or project scenarios that incorporate sophisticated modeling of leakage or spillover.

The challenge of calculating emissions impacts would be much simpler if positive and negative indirect impacts cancel each other out. In practice, the emissions reduction estimates of most projects tacitly employ this assumption. The blanket assumption that indirect impacts are negligible is difficult to justify. Nonetheless, as the next two paragraphs show, possible indirect impacts that push GHG emissions in opposite directions can be identified for energy and forestry projects.

Researchers evaluating Demand-Side Management (DSM) programs in the United States have studied extensively the indirect impacts of energy efficiency projects. In addition to the snapback effect discussed above (money saved on energy may in part be spent on more energy), there exist questions of free riders and spillover (Eto et al. 1995). Free riders are participants in a project that would have adopted the efficiency enhancing measure even without the project. Thus, the presence of free riders would mean emissions reductions are lower than would be estimated by simply looking at the energy savings of the project participants (leakage). However, spillover effects have the opposite impact on emissions estimates. Energy-efficiency projects encourage participants and even non-participants to embrace the new technology after the project is over. Participants will have the customary doubts about new technology assuaged (assuming the technology functions as planned). More generally, projects may lead to market transformation, whereby a project has lasting effects on the market (Vine and Sathaye 1998). For example, after a project has established a technology's worth, it may thereafter continue to win some share, perhaps an increasing share, of the market.

A variety of types of indirect impacts can also be imagined for forestry projects. A forest plantation project could have spillover effects similar to those for energy efficiency projects. The success of forest plantations could encourage other projects. Also, they would increase the supply of timber and create jobs, possibly decreasing deforestation pressure by decreasing prices for timber and absorbing labor (Chomitz 1998).-3 While spillover is feasible, leakage is a particular concern in the case of forestry projects that reduce the availability of forestland to satisfy demand for timber and agricultural land. When it comes to land, there is only so much available for a growing population. A project that protects one area of forest may divert the demand for forest conversion to another area. In the extreme, if the demand for timber or conversion of land to agricultural use is absolutely inelastic (e.g. does not respond to changes in price or other variables), then a forest protection project would have no benefit. All of the demand would be shifted elsewhere, possibly even to another country (Brown et al. 1997).

Although leakage is a matter of particular concern in forestry projects, it is possible to design projects to minimize the effect of negative impacts. For example, a project that aims to return pasturelands to forest could include a parallel effort aimed at increasing the intensity of cattle ranching in other areas (ibid.). Thus, the project would not cause deforestation elsewhere in order to satisfy demand for beef. Higher productivity would allow the existing pastureland to meet demand. While this scenario seems plausible in the short term, the long-term relationship between increased agricultural productivity and deforestation is complex. Does rising productivity increase the output of our current land, decreasing pressure to convert forests? Or does it increase our ability to exploit land, thus increasing the value of land in alternative uses besides forestry and spurring the development of areas hitherto left untouched?

6. Criteria for Evaluation of Baselines and Leakage

Lack of credibility is probably the greatest threat to CDM projects. Concerns about the accuracy of baselines and estimates of emissions reductions are compounded by the incentive for project participants to inflate claims of emissions reductions. If the CDM is to serve as a viable means for mitigating climate change, technical soundness of the baseline and project scenarios must be considered the top criterion. Of course, keeping costs from ballooning will also be necessary if the CDM is to succeed.

The technical soundness of a scenario, baseline or project, can be decomposed into two basic components: (1) methodology, and; (2) empirical data. Technically sound baseline and project scenarios will have to go beyond predicting direct impacts to consider indirect effects. Emissions reduction estimates should address concerns about leakage through either: (1) measures put in place to minimize potential negative impacts, such as displaced deforestation pressure; (2) advanced statistical and computer modeling to predict cumulative impacts.

Predicting the future is an inherently uncertain endeavor. Deforestation is an exceptionally complicated process involving diverse socio-economic and natural phenomena that interact dynamically. At the same time, substantial progress has been made in the last decade in modeling deforestation. In particular, the incorporation of spatial aspects of the process through the use of satellite data and more advanced Geographic Information Systems (GIS) software have improved model performance.

One basic element of any baseline scenario is the empirical data upon which it is based. The quality of remote sensing data and methods for interpreting satellite images far exceed state-of-the-art technologies from just a few years ago. There is movement toward a global system to monitor the state of and changes in land cover and land use with a special emphasis on tropical deforestation. Key issues in data quality are the resolution of the images being analyzed and the procedures used to interpret the data.

As deforestation models and access to and quality of data improve in the future, sophisticated predictive modeling may emerge as the clear minimum technical requirement. Today, simpler (and less costly) methods for modeling and predicting deforestation, such as extrapolation, cannot be categorically rejected as technically inadequate. Nonetheless, baseline credibility will be enhanced if more advanced methods of modeling land use/cover change are employed. More sophisticated modeling techniques are particularly appropriate for larger projects in which case the transaction costs for such modeling will be a relatively smaller percentage of the project's total cost. One possibility is for simpler methods to be used at first and then more expensive and time-consuming methods can be developed over time to increase accuracy of ex-post estimates. SGS's continuous improvement approach offers a framework for considering new information and understanding after a project has been implemented.

In addition to technical soundness, transparency can contribute to a project's credibility. Results, and just as importantly assumptions and methods should be explained and justified. Emissions reduction estimates based on scientifically sound methods that are made available to public scrutiny can only enhance investor confidence. Alternatively, mysterious black box approaches to predicting carbon benefits may foster uncertainty.

PART TWO: THE CASE STUDY

7. Overview of Costa Rica's Protected Areas Project

The Protected Areas Project (PAP) aims to finance the purchase and protection of approximately 555,000 hectares of land within 27 of Costa Rica's National Parks and Biological Reserves. 530,500 hectares of this land has mitigation potential, including 422,800 hectares of primary forest and 107,800 hectares of secondary forest or pasture. 24,500 hectares comprise rivers, lakes, and wetlands within the project's boundaries that are not suitable for producing emissions reductions. The Costa Rican Joint Implementation Office (OCIC) is implementing the project in cooperation with the National System for Conservation Areas, the National Parks Foundation, the Costa Rican Earth Council Foundation, and the Ministry for Energy and Environment.

The OCIC estimates that the project will produce approximately 15.7 million tonnes (Mt) in carbon savings if the project is fully funded and implemented.[7] This GHG emission mitigation potential is derived from both forest conservation (protection of carbon stock) and enhanced natural regeneration (carbon sequestration). About three-quarters of the projected carbon benefits, 11.7 Mt, are based on conservation of primary forest. The remaining 4 Mt of the carbon benefits are based on natural regeneration. Biomass will be allowed to grow back on pastureland and secondary forest growth will be allowed to continue without human interference.

Costa Rica has an impressive system of protected areas that covers 24% of the country. Yet, the demarcation of National Parks and Biological Reserves was not followed by the purchase of the land within their borders in many cases. Before the initiation of the PAP, only 5.4% of the land within Costa Rica's protected areas has been paid for and added to the list of lands protected as part of the nation's natural patrimony. Moreover, recent constitutional rulings have prohibited the government from limiting the rights of property holders unless they are fairly compensated. These constitutional rulings, as well as the

[7] The USIJI Uniform Reporting Document available through the UNFCCC's web site ((http://www.unfccc.de) indicates that the carbon dioxide benefits of the project amount to 57,467,000 tonnes. This translates into 15.7 Mt of carbon.

Costa Rican Government's assertion that it lacks funding to pay for more land, serve as the basis for the PAP's claim of additionality. It seems clear that forests in Costa Rica's National Parks and Biological Reserves will be subject to a heightened risk of deforestation in the future if the PAP does not succeed. Therein lies the opportunity for foreign investors to help contribute to forest conservation in Costa Rica's protected areas.

The OCIC plans to conclude consolidation of the land within the PAP in 2003, five years after initiation of the project. Consolidation is defined as the process of purchasing land and registering it as property of the state. Forest conservation and enhanced natural regeneration brought about by consolidation will produce carbon offsets that are to be sold to fund the project. Consolidation will guarantee the protection of the land for 20 years. Therefore the project's duration will be 25 years. Thereafter, the project proponents assert that the land will be protected in perpetuity as part of Costa Rica's system of protected areas. Permanence is a term used to describe emission reduction benefits that continue beyond the end of the project. Given the progress Costa Rica has made in reducing deforestation inside protected areas in the last decade, this claim of permanence seems credible.

An independent third party, SGS Forestry of SGS International Certification Services, will monitor, evaluate, verify and certify that projected carbon offsets produce real emissions reductions. Data collection techniques will include a combination of fieldwork, aerial photography, and remote sensing data. Monitoring and verification over the life of the project will entail making sure that primary forest remains undisturbed and that forest regrowth is occurring as anticipated.

8. The History of Deforestation in Costa Rica

8.1. Rates and Patterns of Deforestation

Scientists have studied no country in the tropics more intensely than Costa Rica on a per capita or per square kilometer basis. Consequently, less uncertainty exists about Costa Rica's deforestation rates, patterns, and the processes underlying them than exists generally about tropical deforestation. Still, different definitions of forest cover and technical limitations have resulted in some substantial variation in deforestation estimates. Nonetheless, some general conclusions and broad trends are clear. The research shows large-scale, rapid deforestation starting about 50 years ago. Then, in about the mid-1980s, deforestation slowed markedly. To reflect the decrease in deforestation rates in recent years, the discussion of the literature on deforestation rates is divided into two sections—historical (pre-1985) and recent (post-1985),

As a result of deforestation, primary forest in the densely populated Central Valley and the Pacific Northwestern area of the country have almost completely disappeared. The land in these areas is generally most well suited to agriculture and drier, which means it is relatively easier to burn the forest to clear it (Sader and Joyce 1988). Remaining forests are concentrated along the central cordilla, the mountain range running through the center of the country, which have received some natural protection from steep slopes and inaccessibility (Sanchez 1998). From 1986-1997, most deforestation occurred along the Caribbean coast and in the country's northeast in particular (FONAFIFO 1998).

8.1.1. Historical Deforestation (Pre-1985)

By all accounts, Costa Rica has experienced one of the most rapid deforestation rates in the world. An influential study by Sader and Joyce (1988) estimated primary forest as a percentage of Costa Rica's 51,000 km^2 in territory for 1940-1983. Their findings are summarized in Table 2:

Table 2. Primary Forest Cover as a Percentage of National Territory

Year	1940	1950	1961	1977	1983
Forest as % of national land	67%	56%	45%	32%	17%
Deforestation rate since previous estimate (hectares/year)		55,600	51,000	43,000	76,500

Source: Sader and Joyce (1988)

Sader and Joyce's study examined the area covered by primary forest, which they define as relatively undisturbed natural forest with upper canopy coverage of at least 80%.

Recent studies have shown that Sader and Joyce greatly underestimated the amount of forest cover remaining in the two later periods. The literature on deforestation in Costa Rica is summarized in Table 3. The main source of Sader and Joyce's error can be attributed to their use of relatively large mapping units that led them to miss smaller forest fragments. This underestimation of the total extent of primary forest became problematic in the later years of the study when as deforestation progressed and remaining forest covered became increasingly fragmented. Sader and Joyce themselves suggest that they underestimate forest cover, especially in later years, due to their methodology.

Although Sader and Joyce's (1988) findings on remaining forest cover may overstate the amount of forest clearing, the rate of deforestation their study suggests over the 1940-1980 time period is broadly similar to the rates found by other studies. Sader and Joyce's study suggests that Costa Rica's deforestation rate increased from about 2% per year in the 1940's and 1950's to about 3% per year in the 1970's. Leonard (1987) has estimated that Costa Rica lost on average 3.9% of its forest cover per year from 1950 - 1984. The high rate of deforestation Sader and Joyce (1988) estimate for the 1977-1983 interval is not far from the peak rate of 70,000 hectares per year estimated by Keogh (1984) that is the highest rate cited in the literature for Costa Rica.

Other studies have found larger percentages of forest cover remaining in Costa Rica, but, again, the rates of deforestation reported do not differ substantially from the broad trend estimated by Sader and Joyce. R.M. Keogh's (1984) study over roughly the same time period reports estimates of national forest coverage that are consistently about 10% higher than those found by Sader and Joyce. Keogh found primary forest coverage to be 76.5% of national territory in 1943, 63.4% in 1960 and 41.7% in 1977. Thus, for the 1943-1977 time period, the average annual rate of deforestation was 52,000 hectares per year.

Tschinkel (1988) found 50% of Costa Rica covered by forests in 1970 and 31% covered in 1983. This amounts to more than 55,000 hectares per year deforested annually. The Costa

Rican forestry agency, the Dirección General Forestal (DGF), has also estimated yearly deforestation in the late 70's and early 80's as essentially unchanged from earlier times at a level of 50,000 hectares per year (Edelman 1995).

Another study using more advanced satellite images (Sanchez 1996) found Costa Rica's remaining forest cover to be much more extensive than Sader and Joyce's (1988) estimate of forest cover in 1983. The satellite images used in the study covered 93% of the country, but clouds obscured 17% of the images. Moreover, two areas of forestland, in the north and the Osa Peninsula, fell outside of the 93% of the country included in the study. Still, Sanchez (1996) was able to find 32% forest cover in 1986 and 29% forest cover in 1991. Sanchez attributes the difference to the large mapping units used in Sader and Joyce's study that caused them to ignore smaller areas of natural forest. Over the 1986-1991 period, Sanchez found that deforestation occurred at a rate of approximately 45,000 hectares per year.

8.1.2. Recent Deforestation (post-1985[8])

The studies reviewed above essentially agree that that the rate of deforestation was roughly 50,000 hectares per year before about 1985. One study of deforestation before 1985 did find a lower rate of deforestation. The study, conducted jointly by the World Resource Institute (WRI) and the Costa Rica-based Tropical Science Center (TSC), found a decrease in the rate of deforestation from 48,800 hectares per year for 1966-1973 to 31,800 hectares per year for 1973-1989 (Solorzano et al. 1991). While lower than other estimates, the estimate of deforestation for the 1973-1989 period still amounts to about 1.2% to 1.8% annual deforestation, which is two to three times the international average over that time period (ibid.). The WRI/TSC study found forest cover to account for 58.5% of national territory in 1966 and 42.9% in 1989. This study was the first to recognize that deforestation had begun to slow in Costa Rica. It was also the first to indicate the true extent to which earlier studies such as the one by Sader and Joyce (1988) had underestimated the amount of

[8] The dividing line for "recent" and "historical" deforestation is artificial although not completely arbitrary. The later time period is intended to broadly capture the onset of decreasing deforestation rates in Costa Rica.

forest cover remaining. The WRI/TSC used satellite data with much higher resolution, 1:60,000 compared to the 1:300,000 level of resolution used by Sader and Joyce.

Other studies support the conclusion that deforestation has slowed in Costa Rica. One study (Sanchez et al. 1998) suggests that in one region of the country outside of protected areas deforestation rates are rising after a temporary slowdown in the late 1980's and early 1990's. However, the broad trend, supported by original LBNL analysis discussed in Section 9 of this paper, has been a slowing of deforestation rates nationally over the last decade or 15 years.

An interdisciplinary fact-finding mission conducted by the World Bank and CATIE (Centro Agronomo Tropical de Investigation y Ensenanza, or Tropical Agricultural Center for Research and Education) estimated that by 1993 deforestation had fallen to a rate of about 5,000 or 10,000 hectares per year from a rate of about 30,000 hectare per year, "in past periods,"[9] (Lutz et al. 1993). The report observes that at the time the largest single category of land use for permanently cleared forestland was banana plantations, which they estimate consumed about 500 hectares of forest per year. Lutz et al. (1993) suggest that a decrease in deforestation rates can be explained in part by the fact that in the past conversion of forested land took place on the land most suitable for agricultural use.

Kishor and Constantino (1993) also suggest that Costa Rica's deforestation rate has decreased. They found that from a level of 50,000 hectare per year, the rate of deforestation slowed down to 17,000 hectare per year for the 1988-1992 interval, "in part because there were very few forests left to convert," (Kishor and Constantino 1993, p.2).

A recent study of Costa Rica's Sairaquipí region offers some evidence that a slowdown in deforestation rates in the late 1980's was followed by a return to earlier faster rates in the 1990s at least for forestland outside of protected areas (Sanchez et al. 1998). The study is the first to examine the different rates of deforestation inside and outside of protected areas.

Sanchez et al. found deforestation in protected areas in the Sairaquipí region to have declined from an annual rate of 0.56% between 1976-1986 to 0.21% from 1986-1991 and to 0.16% from 1991-1995. Outside of protected areas the annual deforestation rate fell from 3.6% over 1976-1986 to 2.8% between 1986-1991, and then the rate rebounded over the 1991-1995 interval to a level of 3.2%. A third land tenure type – private conservation areas outside of the government's protected areas – was also considered in the analysis. The deforestation rate on such lands decline from 1.7% from 1976-1986 to 1.4% from 1986-1996.

The surge in deforestation outside of Sairaquipí's protected areas appears to be an anomaly. A comprehensive national study using recently compiled, technologically advanced Landsat data for 1986-1997 shows that deforestation nationally slowed to a rate of about 1% per year (FONAFIFO 1998). The FONAFIFO study also found 40% forest cover in 1997. This 40% figure includes secondary growth forest that is at least 10 years old, but it is not clear that forest regrowth can account for the relatively large size of this estimate of today's forest cover as compared to estimates of forest coverage in the 1980's. Regardless, it is clear that a 1% deforestation rate is much lower than estimates of 3% to 4% clearing of national forest cover in earlier decades.

LBNL attained access to the FONAFIFO land use, land cover data set and conducted a disaggregated analysis of protected areas versus the land in the 10-kilometer boundary zones upon which the OCIC's baseline deforestation rates are based. LBNL's analysis shows the slowing trend has been broadly mirrored by both categories, inside protected areas and in their peripheries. In both cases, deforestation rates decreased in 1986-1997 from their levels over the time period 1979-1986.

Table 3 summarizes the literature on Costa Rican deforestation, historical and recent.

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[9] The authors cite the Solorzano et al. (1991) which estimated deforestation at 30,000 hectares/yr. for 1973-1989.

Table 3. Summary of Studies of Deforestation in Costa Rica

STUDY	FINDINGS
Historical (pre-1985)	
Sader & Joyce (1988)	Forest cover: 1940 - 67% 1950 - 56% (deforestation rate of 55,600 hectares/year) 1961 - 45% (51,000 hectares/year) 1977 - 32% (43,000 hectares/year) 1983 - 17% (76,500 hectares/year)
Keogh (1984)	Forest cover: 1943 - 76.5% 1960 - 63.4% (deforestation rate of 29,000 hectares/year) 1977 - 41.7% (65,000 hectares/year)
Tshcinkel (1988)	Forest cover: 1970 - 50%; 1983 - 31% (deforestation rate of 55,000 hectares/year)
Leonard (1987)	Deforestation rate of 3.9% per year for 1950 - 1984
Solorzano et al. (WRI/TSC, 1991)	Deforestation of 48,800 hectares/year for 1966-1973, and 31,800 hectares/year for 1973-1989 (=less than 1.5%) Forest cover: 1966 – 58.5% 1989 – 42.9%
Recent (post-1985)	
Lutz et al. (1993)	Early 1990's deforestation rate: 5,000 - 10,000 hectares/year
FAO (1993)	Deforestation rate of 2.9% in late 1980's; likely overestimated due to data limitations.
Sanchez (1996)	Deforestation rate of 45,000 hectares/year or about 2% (1986-1991) Forest cover: 1986 – 32% 1991 – 29% (Forest cover figures do not include the Osa Peninsula or part of northern Costa Rica that include large areas of primary forest.)
Kishor & Constantino (1993)	Deforestation rate for 1988 - 1992: 17,000 hectare/year
Sanchez et al. (1998)	Deforestation rates for the Sairaquipí region: (1) Within Protected Areas: 1976-1986 – 0.56% 1986-1991 – 0.21% 1991-1995 – 0.16% (2) Outside Protected Areas (not including private conservation areas) 1976-1986 – 3.6% 1986-1991 – 2.8% 1991-1995 – 3.2%
FONAFIFO (1998)	Deforestation rate: 1% per year between 1986 and 1997 Forest cover: 1997 – 40% 1986 – 32% (this year's data does not include the Guancaste region)
LBNL (1998)	Analysis of deforestation rates inside protected areas and in areas surrounding them found both decreasing from 1979-1986 to 1986-1997. Full results of LBNL's analysis reported in Table 4.

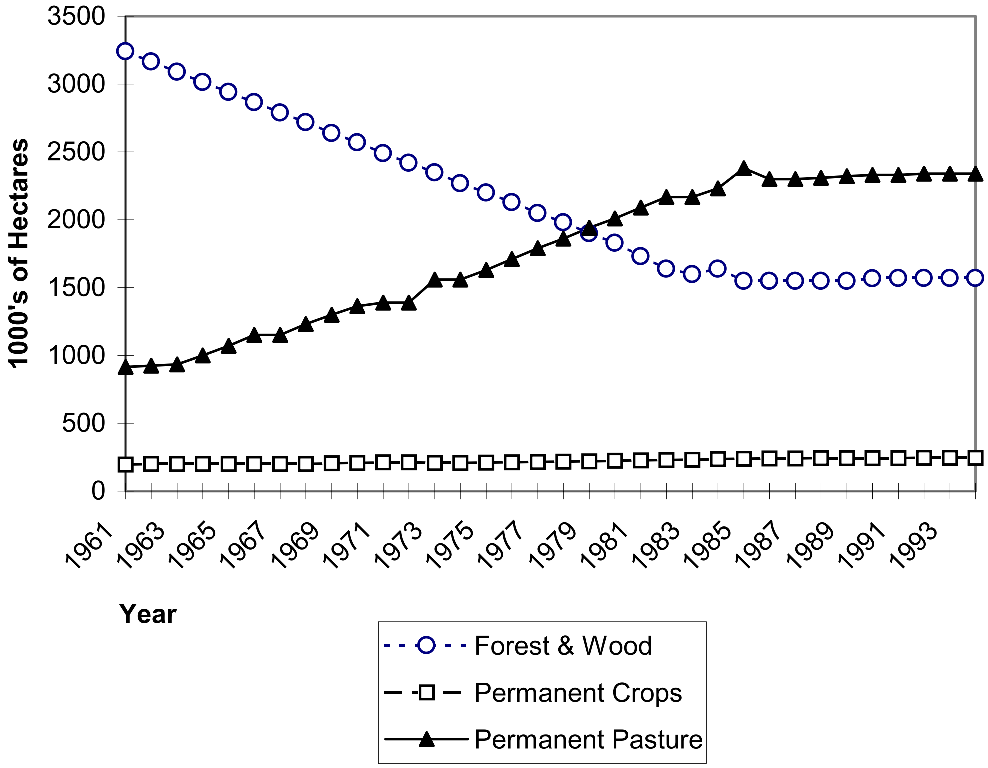
8.2. Dynamics of Deforestation in Costa Rica

Analysis of deforestation typically distinguishes between the underlying causes of deforestation and the human activities that cause deforestation. The general dynamics of deforestation are discussed further in the Appendix. The discussion below focuses on the Costa Rican experience.

8.2.1. Activities

In Costa Rica, the conversion of forest to pasture land for cattle ranching has been the single most important human activity resulting in deforestation (Lutz and Daly 1991). The environmentalist Norman Myers coined the phrase, “The Hamburger Connection,” to describe the role of production of beef for export to North America in Central American deforestation (Myers 1981). The theory of a Hamburger Connection has been criticized for ignoring the role of domestic demand for beef in the region’s deforestation (Edelman 1995). Still, whether the driving force was domestic or foreign, the primary role of conversion of forest to pasture land is clear (Kaimowitz 1996). Figure 1 shows the decrease in forested land over time corresponding to the increase in pastureland. The data are annual, and show the more than doubling in the area of pastureland from 1961 to 1989 while the area of Costa Rica covered by forest fell by more than 50%.

Figure 1: Costa Rican Land Use, 1961-1994



Source: U.N.F.A.O. land use statistical database (FAO 1998).
Comment: The Forest & Wood category includes second-growth forest and wood plantations, not just primary forest.

Although conversion of forests to pasture land has been far and away the most important human activity behind deforestation in Costa Rica, expansion of permanent agriculture and the spread of urban areas have also played important roles. Particularly notable is the clearing of large tracts of forest in the Central Valley for residences and other urban infrastructure (Sader and Joyce 1988). Squatting by landless migrants who engage in subsistence farming has led to deforestation in the past, but the impact has been small compared to large-scale agriculture, and declining in recent years (Lutz and Daly 1991; Lutz et al. 1993). Other human activities such as gold mining and hydroelectric dam building have played important roles in land use change in various regions. Logging is an increasingly important proximate cause of deforestation throughout the country (Edelman 1995).

8.2.2. Causes

The causes, or driving forces, of Costa Rican deforestation have been varied, but a few can be identified as key: (1) public policies (mainly frontier settlement and economic development policies that created incentives for clearing forests); (2) market imperfections and failures; (3) short-term profit motive; (4) consumer demand; (5) population growth; (6) cultural values.

A chief driving force has been public policies that created disincentives for forest protection and incentives for clearing the land and using it in other ways. Until fairly recently, Costa Rican law allowed settlers to claim land if they cut down the forest to show that they were using it productively. This practice dates back to an 1892 Costa Rican law, the Ley de Cabezas de Familia, that allowed settlers to claim ownership of public wilderness lands if they cleared and farmed the land. In 1942, the Ley de Poseedores en Precario extended this principle to private lands. Squatters, "precaristas," could claim title to previously undisturbed forests if they cleared and cultivated the land (Harrison 1991). Such land-titling policies were reinforced by low land taxes that provided little disincentive to those who would claim land (Peuker 1991).

These early land tenure laws reflected and contributed to a cultural ethos that conceived of forests as having no value or even as obstacles to progress. Although Costa Rica has changed laws associating forest clearing with ownership, changing popular beliefs about the value of forests and the need for sustainable management of the land is an ongoing process.

The key driving force in Costa Rican deforestation has been government policies to promote economic development, mainly agricultural development, which have increased the value of the land for uses other than forestry. These policies generally took the form of subsidized loans. Early deforestation, in the 1950s and early 1960s, resulted from policies aimed at promoting commercial crops such as coffee and sugar cane as well as land settlement policies instituted by Costa Rica's Land Colonization Institute that promoted subsistence farming (Sanchez 1998).

In the later 1960s and 1970s, government policy shifted to the promotion of cattle ranching, especially the production of beef for export (ibid.). However, by the mid-1980's, the government had begun dissembling policies favoring agricultural development (Sanchez 1998; Harrison 1991). U.S. laws limiting foreign beef imports and a decline in international beef prices also played a role in the collapse in demand for new land for pasture (Edelman 1995).

While a change in incentives facing landowners contributed to the marked slowdown in conversion of forests to pastures that is evident in Figure 1, by many accounts the best land for agriculture (including cattle ranching) had already been cleared of forest. A study of land use in 1984 found that 44% of Costa Rica's land is suited for agricultural use while 56% is suited for forest use, while in actuality 58% of the land was being used for agriculture and only 34% was forested (Kishor and Constantino 1993). Of the land classified as suitable for agriculture, less than 25% (466,000 hectares) is considered best used as pasture. However, in 1984 the amount of land devoted to pasture was about four times this amount, 2 million hectares (FAO 1998). The cattle sector had expanded based on extensive exploitation of the land rather than increasingly intensive exploitation (Sanchez 1998). Much of the land currently in pasture could be used more productively and intensively to farm crops.

Another area of public policy that has contributed to deforestation is infrastructure development. Costa Rica has one of the densest road networks in the developing world (Peuker 1991). Extensive road building has served in effect as a public subsidy for those who would convert forests to other uses. Roads lower the cost of transporting timber and agricultural products to market. Sader and Joyce's (1988) study found a strong relationship between the transportation network and forest clearing. Few tracts of forest remained in proximity to roads or railways by 1977 and 1983. Cumulative road length more than doubled from 2088 km to 5582 km from 1967 to 1977. The mean distance from the nearest road or railroad to forest dropped from 14.2 km to 5.5 km over the same time period (Sader and Joyce 1988).

In addition to public policies that created disincentives for forest conservation, market failures and market imperfections have also contributed to deforestation. Forests provide ecological services that benefit society as a whole, but these benefits (and the costs imposed when the ecological services disappear) are not internalized in the decision-making of private landholders. The failure of the market to include these costs and benefits leads to excessive and economically inefficient levels of deforestation.

Economic development policies, market failures, and the opportunity for short-term profit combined to give private landholders the incentive to convert forests to cropland and pasture. Another key element was consumer demand. Without demand for beef and other agricultural products, the incentive to cut down forests would not have been so strong. The Hamburger Connection theory, briefly mentioned above, identifies the role that foreign demand for beef played in deforestation (Myers 1989). The increasing integration of Costa Rica's economy with the global economy means that global demand and increasing affluence have contributed to the creation of a profit motive. However, increasing domestic demand has also played a role. Costa Rica's population has grown rapidly while per capita beef consumption grew as well. In 1960, Costa Rican's consumed about 10 kg of beef on average per year. By 1990 that figure had grown to about 20 kg per capita annually (Edelman 1995).

Costa Rica's rapid population growth, the country has had one of the highest rates of increase in the world (Cruz et al. 1992), would seem to be an obvious factor in increasing domestic demand for agricultural and timber products and demand for land for urban development. Nonetheless, there is debate about whether population growth can be considered an important driving force in Costa Rica. One study found little correlation between deforestation and population growth (Harrison 1991). The most revealing result of the study was a statistically significant correlation between decreasing forest cover and migration to frontier areas (outside of the Central Valley and Pacific regions). A more recent study has indicated that population has not played an important role in land cover change in Costa Rica (Rosero and Palloni 1997). This study agrees with an earlier analysis by Lutz and Daly (1991) that found that profit and asset maximization motives, not population growth, have driven deforestation in Costa Rica.

Although there is ample evidence that the opportunity for short term commercial profit underlies the conversion of forests to pasture and cropland, a World Resource Institute study of Costa Rica argues that population growth, poverty and inequality should not be dismissed as driving forces (Cruz et al. 1992): "Population increases and mismanaged agricultural policies have combined to convert many fragile lands to pasture and cropland. The poverty of a sizeable percentage of Costa Ricans has also contributed to the degradation of the nation's forests and soils. Then too, the unequal distribution of wealth translates into pressure to increase cultivation on small farms and to migrate to more marginal or invadeable resources," (Cruz et al. 1992, p.51).

The role of logging as a driving force of deforestation in the past has been limited. One study found that the amount of lumber harvested commercially in the 1960's and 1970's amounted to less than 10% of the volume of trees cut down to clear the way for pasture or crop land (Tosi 1980). Despite the relatively minor role of logging in the past, there are indications that demand for timber and wood products may be a key driving force in the future: in 1990, the President of the Costa Rica-based Tropical Science Center observed that, "the country is in a transition stage. Wood [not cattle] is becoming the most important factor in deforestation," (Edelman 1995, p.34).

The end of massive conversion of forests to pasture land does not signal the end of deforestation in Costa Rica. Increasing wood scarcity and the limited amount of land that remains outside of protected areas means that Costa Rican forests remain at risk. Sader and Joyce (1988) found wetter lifezones and steeper slopes to offer some protection to forests.

However, poor soils and steep slopes are more important barriers to agricultural development than to logging. Moreover, Sader and Joyce's analysis of forest cover over time in the Central Valley found that steep slope gradients offer only incomplete protection for forests. Their study found that, "by 1983, an inverse linear relationship existed between primary forest reduction and slope gradient, but even slopes >60 percent supported less than one-third of the total area in original forest," (Sader and Joyce 1988, p.17). The implication is that socio-economic driving forces can overcome even apparently substantial geographic barriers to development.

9. LBNL's Analysis of Costa Rican Deforestation Rates

Indications in the literature that Costa Rica's conservation efforts had started reducing deforestation in the mid-1980s led LBNL to further investigate recent deforestation trends. The FONAFIFO national forest cover data for 1986-1997, which shows a broad decline of deforestation rates from a level of about 3% or 4% per year to 1% annually, was acquired. Deforestation rates were found for inside protected areas and in the areas surrounding them. Such a disaggregated view allows more accurate spatial description of deforestation trends.

9.1. FONAFIFO's 1986 and 1997 Data Sets

FONAFIFO's 1986 and 1997 data sets were developed by the Tropical Science Center and the Research Center for Sustainable Development of the University of Costa Rica. A total of 6 Landsat TM 5 satellite scenes with a maximum cloud cover of 20% were acquired for this study. The environmental group Conservation International has certified the quality control procedures used and the final product itself. The final map was produced at a scale of 1:250,000. The Costa Rican government is adopting the map as official government data.

Satellite images were classified and interpreted following quality control procedures established by the NASA Pathfinder Tropical Deforestation Project, also known as the Landsat Pathfinder Project (Chomentowsky et al. 1994; Skole and Tucker 1993). The minimum mapping unit was 3 ha. Final land cover and land use classes were forest, non-forest, mangroves, secondary forest and deforested area.

More than 300 control points per scene were used for georeferencing. The georeferencing error is estimated to be less than 25 m overall. A total of 456 ground control points selected by the Tropical Science Center were used for accuracy assessment. Point distribution indicates that 42% of this sample came from forested areas and 58% from non-forest areas. Overall accuracy for the final map is estimated at 88%, e.g. 402 of the 456 ground control points were found to have been classed accurately for the map as a whole. Accuracy for the forest class is 90% (85-95%). Numbers in parentheses represent a 95% confidence interval for the actual accuracy of the classification. Non-forest class accuracy is 94% (91-97%).

9.2. Deforestation Rate Analysis

Using the FONAFIFO (1998) data sets described above and the 1979 data set, LBNL conducted an analysis of deforestation rates inside National Parks and Biological Reserves and in a 10 kilometer peripheral zone around these protected areas as called for by the OCIC's baseline methodology. The purpose of LBNL's analysis was to better illuminate recent trends in deforestation in Costa Rica. Does the national slowdown in deforestation reported by FONAFIFO mask increased deforestation rates elsewhere? Was the slowing of deforestation evident both inside and outside of protected areas? How different are deforestation rates in protected areas compared to the rates in boundary zones? The results of this analysis along with the deforestation rates in the boundary zones over the 1979-1992 period that are used as the basis for the OCIC's linear extrapolation are summarized in Table 4.

Table 4. Deforestation Rate Analysis

Name of Protected Area	Def. Rate in Protected Area 1979-1986 (%/yr)	Def. Rate in Protected Area 1986-1997 (%/yr)	Def. Rate in 10km Boundary Zone Outside P.A. 1979-1986 (%/yr)	Def. Rate in 10km Boundary Zone Outside P.A. 1986-1997 (%/yr)	*Def. Rate in 10km Boundary Zone Outside P.A. 1979-1992 (%/yr)
Alberto Manuel Brenes	2.71	0.00	5.74	0.68	3.29
Amistad	4.38	0.02	2.76	0.47	1.26
Arenal Volcano	1.62	0.35	5.74	0.68	3.29
Barbilla	0.12	0.27	2.76	0.47	1.26
Barra Honda	0.00	0.00	4.74	0.00	2.29
Braulio Carrillo	0.00	0.04	5.94	1.16	0.84
Cabo Blanco	0.00	0.00	0.00	0.00	22.3
Cahuita	8.01	0.00	5.73	1.13	1.26
Carara	1.26	0.10	7.34	0.22	0.84
Cerro las Vueltas	0.43	0.00	2.76	0.47	1.26
Chirripo	0.00	0.04	2.76	0.47	1.26
Corcovado	2.59	0.07	3.90	0.43	1.2
Guanacaste	6.34	0.22	8.85	0.53	3.25
Hitoy Cerere	0.93	0.02	2.76	0.47	1.26
Irazu Volcano	4.87	0.46	5.94	1.16	0.84
Juan Castro Blanco	0.60	0.16	5.94	1.16	0.84
Lomas de Barbudal	0.00	0.00	4.74	0.00	2.29
Manuel Antonio	0.00	0.14	11.79	1.08	10.5
Palo Verde	4.95	0.00	4.74	0.00	2.29
Piedras Blancas	1.52	0.11	3.90	0.43	1.2
Poas Volcano	0.58	0.03	5.94	1.16	0.84
Rincon de la Vieja V.	1.63	0.22	8.85	0.53	3.25
Santa Rosa	2.18	0.00	8.85	0.53	3.25
Tapanti	0.14	0.11	2.76	0.47	1.26
Tenorio Volcano	0.00	0.09	5.76	2.35	3.29
Tortuguero	0.36	0.03	3.01	1.63	2.15
Turrialba Volcano	0.03	0.22	5.94	1.16	0.84
Total**	2.61	0.056	4.53	0.614	1.75

Sources: FONAFIFO (1998), SGS (1998), IMN (1979 & 1992 data sets)

*This gray column represents the deforestation rates used as empirical inputs to the OCIC baseline methodology.

** The total is the average weighted according to the size (area of primary and secondary forest).

Figure 2: Deforestation Rates in 10KM Buffer Outside Protected Areas

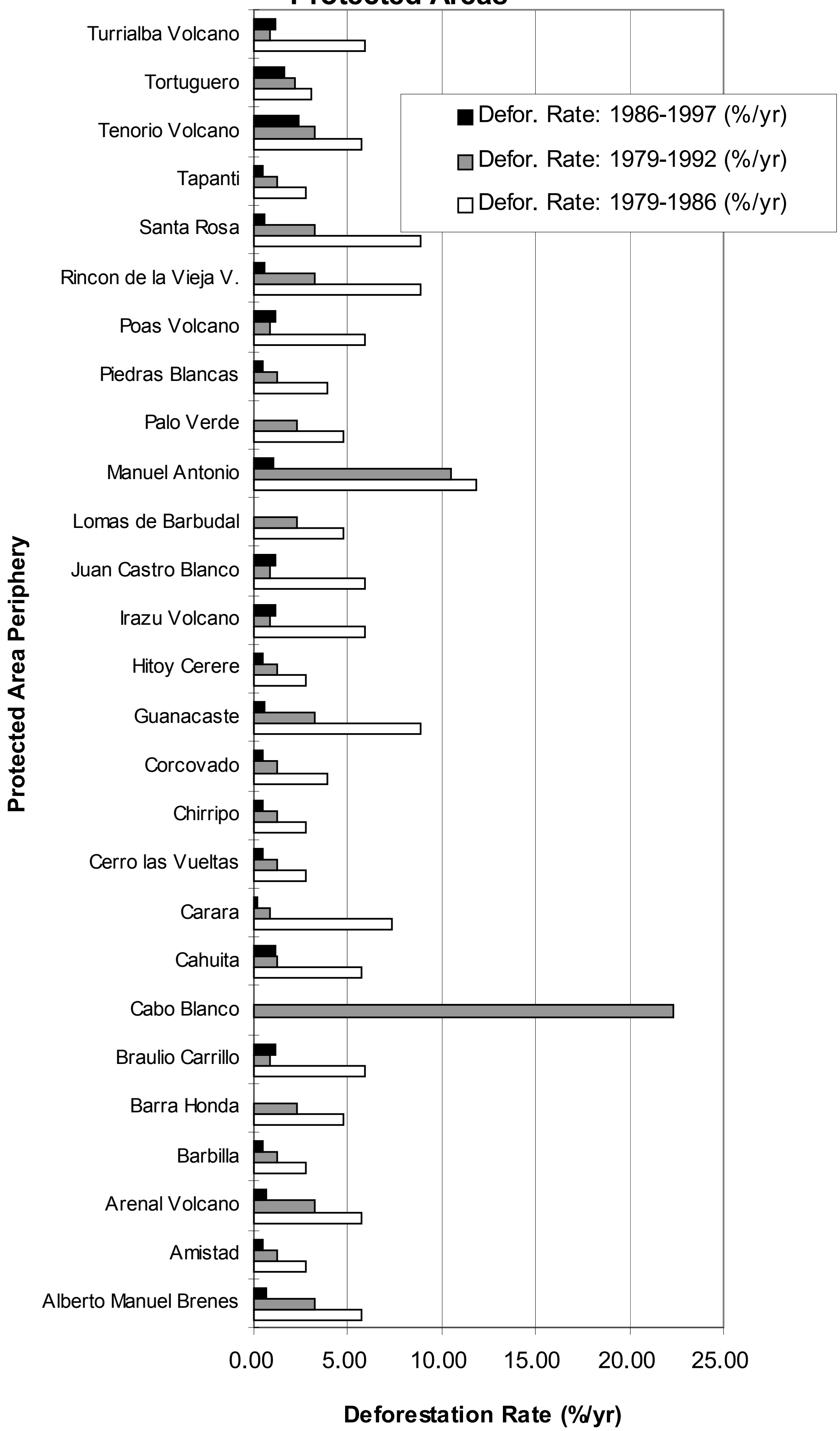
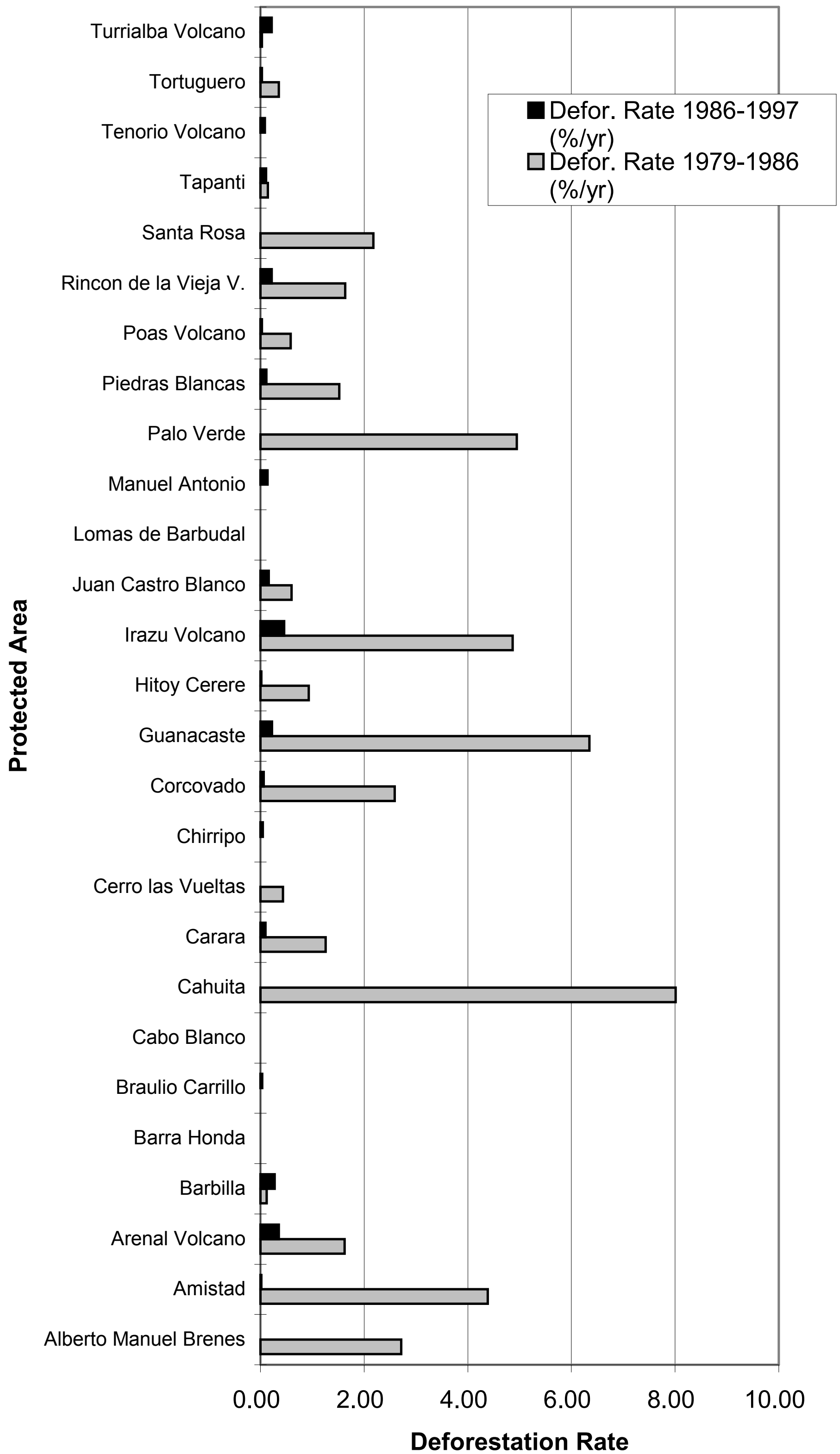


Figure 3: Deforestation Rates Inside Protected Areas



Two basic patterns are apparent from LBNL's work on deforestation rates. First, the analysis shows that deforestation has proceeded at a slower pace inside of protected areas than in the areas bordering them. Secondly, the analysis indicates that deforestation rates have slowed in recent years both inside protected areas and in areas bordering them. Deforestation rates inside National Parks and Biological Reserves slowed markedly to almost zero (0.056%) from 1986-1997.

10. The Baseline for the Protected Areas Project

10.1. Description of PAP Baseline Methodology

SGS and the OCIC employ two distinct methods for constructing baseline scenarios: one for primary forest conservation and another for enhanced natural regeneration on secondary growth forestland or pastureland. Key to the baseline for primary forest protection is the imputation of baseline deforestation rates, e.g. the prediction of deforestation rates that would occur without implementation of the project. The key assumption for natural regeneration is that spontaneous biomass regrowth on pastureland and secondary forestland (which sequesters carbon) and deforestation (which emits carbon) will equal each other, thus resulting in constant carbon content. First this section will discuss in greater detail the approach for primary forest protection and then it will turn to forest regeneration. Next, the empirical basis for imputation of baseline deforestation rate is examined. The last part of the section offers an overall assessment of the baseline and the project's treatment of leakage.

Forest Conservation

Imputation of baseline deforestation rates is critical to the estimation of GHG benefits due to conservation of primary forestland. Deforestation rates observed in 10 km boundary zones surrounding each protected area over the time period 1979-1992 serve as the empirical basis for imputed baseline deforestation rates. Since the protected areas have been well shielded from deforestation pressures recently, past trends in deforestation rates within them will not reflect the new threat of deforestation created by the constitutional ruling. Therefore, the OCIC reasonably concludes that past trends in nearby areas will serve as the best empirical basis for predicting the future deforestation pressure each protected area would face without the project. Since many of protected areas are close to each other, many of the 10 km boundary zones around each area overlap. Where this occurs, the boundary zones are joined. On this basis, nine regional baseline deforestation rates are imputed for the 27 National Parks and Biological Reserves included in the PAP.

Such an approach, using past trends in a variable to predict its future path, is referred to as a time series approach. This can be contrasted with a structural approach where the causes underlying a process are known. A structural model predicts the future path of the variable of interest, here, of course, deforestation rates, based on an underlying projection of causative variables. While the OCIC mainly uses a time series approach, the OCIC methodology does have one structural element: land tenure type. For land that is not privately owned, the proposal scales down the rate of deforestation that would be expected for privately-owned land based on an eight-category, land-tenure typology (explained further below).

Thus, the imputed baseline deforestation rate for each parcel of land in the Protected Areas Project depends on two factors: (1) deforestation observed from 1979-1992 in a 10-km peripheral zones of the protected areas of the region within which the parcel of land is located and (2) the risk factor assigned to the parcel's land tenure type. The fraction representing the risk factor is multiplied by the deforestation rate from 1979-1992 observed in a 10-km boundary zone around the protected area in order to ascertain the imputed baseline deforestation rate for each land tenure type in a given protected area. The imputed baseline deforestation rate for a parcel of land X in protected area Y can be represented as (SGS 1998, p.59):

$$\mathbf{D_{XY} = P_Y * R_X} \qquad \text{(1)}$$

Where:

- D_{XY} is the baseline deforestation rate imputed for parcel X in protected area Y
- P_Y is the deforestation rate in the 10km boundary zone surrounding protected area Y
- R_X is the risk factor for parcel X based on its land tenure status as detailed in Table 4 (below)

Eight land tenure types are identified within the project area and each is assigned a different risk level. Private land is considered the riskiest, while land owned by the national government that has been registered as part of the Natural Patrimony of the State is assumed to face no risk of deforestation. Each of the six land tenure types in between these extremes is assumed to have a different risk of deforestation relative to privately held land. Operationally, this is achieved by assigning each of the land tenure levels a different fraction based on the level of risk as shown in Table 5 below.

Table 5. Risk Factors Associated with Land Tenure Types

Land Tenure Type	**Risk Factor**
Nationally-owned and registered as Natural Patrimony of the State	0/7
NGO, non-profit, or other donor-owned	1/7
Land owned by other state institutions (municipalities, ministries)	2/7
NGO-owned pending administrative transfer to the state	3/7
National Reserves (defined by exclusion, subject to private claim)	4/7
Land in administrative or judicial litigation	5/7
Private land in a non-defined legal situation	6/7
Private land	7/7

Source: SGS (1998) table 15

Once the baseline deforestation rate has been found, it is applied on an annual basis from the year of consolidation over the 20-year life of the project in order to project the area deforested in the baseline scenario. In sum, the key assumptions for the forest conservation baseline are:

1. A linear extrapolation based on the 1979-1992 time period is sufficiently accurate. Underlying trends remain substantially unchanged.[10]
2. Deforestation rates in boundary zones of protected areas are an appropriate empirical basis for imputing baseline deforestation inside protected areas.
3. Land tenure risk factors outline in Table 5 correctly account for different deforestation rates on land with different land ownership characteristics.

Enhanced Natural Regeneration

[10] Note that SGS has recommended collection additional data on deforestation and development of a more sophisticated non-linear extrapolation technique. Discussed further in Section 11.

The baseline scenario assumes constant carbon content on pastureland and secondary forestland. Pasture is assumed to contain 10 tonnes of biomass per hectare. The carbon content of pastureland secondary forestland is estimated at one half the carbon content of the maximum for a mature forest in the same life zone.[11] The reasoning underlying the baseline assumption of carbon content is not absolutely clear. At one point, it is indicated that, "the OCIC has assumed overall the amount of secondary forest will remain constant in the baseline scenario assuming that the net losses of biomass due to deforestation of certain areas are compensated by forest growth in other areas," (SGS 1998, p. 47). At another point, SGS (1998, p.62) indicates that the assumption is that there will be no deforestation or growth on either pastureland or secondary forestland. The former reasoning as opposed to the latter seems more reasonable, since, in the absence of human intervention, biomass growth will naturally take place on most pastureland or secondary forestland. With the project, it is assumed that the carbon content of secondary forests and pasture will increase from the base year value until it reaches its maximum carbon content or the project ends, whichever comes first.

For example, consider a hypothetical 1-hectare parcel of land covered by secondary growth forest with a maximum carbon content of 40 tonnes of C (based on ecological life zone type) that sequesters carbon at a rate of 2 tonnes/ha/year. The baseline assumes that the parcel's carbon content will stay constant at 20 tonnes of C. With the project, it is assumed that the parcel of land will contain 20 tonnes of C at the start of the project and will increase by 2 tonnes per year for the next 10 years until it reaches its maximum level at 40 tonnes of C. Thus, the carbon offsets due to the parcel of land would amount to 20 tonnes of C by the end of the project.

The key assumptions for the baseline for secondary forests and pastureland are:

1. Carbon content will remain constant. Countervailing forces of biomass growth and deforestation will offset each other.

[11] Note that two of the eight remaining corrective actions SGS has recommended aim to improving carbon content and biomass regeneration on pastureland and secondary forestland.

2. Initial biomass value of 50% of primary forest for secondary forests (varies by life zone).
3. Initial biomass value of 10 tonnes per hectare for pasture.

10.2. The 1979 and 1992 Data Sets: Description and Limitations

The 1979 and 1992 data sets used in the OCIC proposal were developed in 1994 and 1995 as part of Costa Rica's national inventory of greenhouse gas emissions. Data production was the responsibility of the National Meteorologic Institute (IMN). A team consisting of professionals from the Natural Resources Ministry and the Agriculture Ministry provided support for the database generation. Remote sensing from two different sensors was used: Landsat 4 (Multispectral Scanner, spatial resolution of 80m x 80m with 4 spectral bands) and Landsat 5 (Thematic Mapper, spatial resolution of 25m x 25m and 7 spectral bands). The images were not processed digitally. Data was visually interpreted from black and white photographic products, and fractal boundaries between classes of land cover or land use were determined manually. Final products were printed at a 1:200,000 scale. Five general observations can be made regarding the 1979 and 1992 data sets:

1) Overall Accuracy. It is not clear whether or not standard quality control procedures were followed in generating the maps, nor does it report the overall accuracy of the maps by land use/cover classes as is regularly done for maps derived from remote sensing data (Congalton 1988; Fitzpatrick-Lins 1981).
2) Fractal Errors. There appear to be significant fractal errors in the 1979 and 1992 data, especially the second data set. Fractal errors occur when there is a mismatch between the shape of a remote sensing device's output (e.g. a square) and the boundary of a protected area or the boundary of a class of land cover or land use. The pixels in a digital photograph are square, but protected areas boundaries, forest islands, holes in forest cover, and boundaries between land classes rarely take the form of square corners or straight lines.

3) Classification Errors. The method used for interpretation of remote sensing data, e.g. classification of the data, appears to be another source of error. Lines between land use and land cover types were drawn in by hand on black and white photographs. In general, visual interpretation of remote sensing data is done on color composite photographic products. Even though manual interpretation of black and white photographs has been successful in the Amazon Basin (Skole and Tucker 1993), its applicability in Costa Rica is doubtful due to the country's high level of forest fragmentation.

4) Cloud Cover. Generally, satellite scenes need to have less than 20% cloud cover to be useful for land cover analysis. Thus, remote sensing data is generally acquired for Costa Rica during the dry season, which occurs from January to the end of April. The final maps show no cloud cover at all. It is not clear how this was achieved since it is virtually impossible to find cloud free data sets for Costa Rica. An archive search of Landsat MSS and TM scenes for 1979 and 1992 at the Earth Resources Data Center Data Center indicates that it is impossible to have a wall-to-wall cloud free data set for Costa Rica.

5) Guanacaste. Remote sensing analysis in the Guanacaste region (Costa Rica's northwest region) is critical. The Holdridge life zone classification system identifies this area as a Tropical Dry forest (Holdridge 1988). The Guanacaste's peninsula forest is deciduous (meaning that leaves fall off the trees annually). The data for the Guanacaste province was collected during the dry season when there is minimal cloud cover. This is also the time of year when the trees have lost their leaves. It appears that the OCIC classification mistook secondary forest cover for either bare soil or pastureland. Areas that were actually covered with secondary or emerging deciduous forest were not labeled accordingly. This error was identified during the 1997 forest cover assessment (FONAFIFO 1998). Information for the 1997 assessment was collected during the wet season (April to November), allowing for the extraction of a significant extension of deciduous forest that was never identified before (Sanchez-Azofeifa & Quesada-Mateo 1995).

10.3. Assessment of Baseline for the PAP

In many ways, the PAP has advanced the methodological frontier for forestry projects. The project goes further than any other in developing rigorous and creative approaches to solving the technical challenge of accounting for the GHG impacts of forestry projects. The PAP's credibility is bolstered by the OCIC's retention of SGS International Certification Services, Ltd. as a third-party evaluator. Further, the release of the SGS report of August 1998 has made the approach to estimating carbon benefits due to the PAP relatively transparent. Despite the many strong aspects of the PAP, a number of potential issues are raised that could point the way to further enhancing confidence in projected carbon benefits. This assessment first considers the technical strengths and weaknesses of the PAP baseline. The next part addresses leakage. Lastly, the assessment considers alternative methods of modeling deforestation that could be employed to further enhance the baseline's credibility.

The methodology and data are presented and critically discussed, and assumptions are clearly stated and summarized.

Baseline Strengths

The OCIC has taken at least three steps to guard against the overestimation of carbon savings.[12] There are two aspects related to the estimation of carbon flows associated with deforestation in the baseline, and a third that concerns the types of human activities considered in the baseline: (1) the choice of carbon stocks and flows measured does not include some that would increase estimates of carbon savings; (2) the omission of GHG benefits other than carbon dioxide emission reductions, and; (3) the focus on emissions reduction due to deforestation when selective logging would lead to some emissions as well in the baseline scenario. Furthermore, SGS has recommended that some carbon offsets be retained in a buffer to account for uncertainty with respect to the baseline. This last point is discussed further in Section 12.

[12] Personal communication from Pedro Moura Costa and Marc Stuart (December 1998) form the basis for this expanded discussion of reasons that the PAP baseline may underestimate carbon savings.

1. *Analysis of Carbon Pools***.** The OCIC's measurement of carbon stocks and flows is conservative (e.g. a factor suggesting underestimation of GHG benefits) as a number of carbon pools are not included that would increase the project's GHG benefits. Consider the example of carbon pools relevant to forest conservation. Only the stock and flow of trees are included in the calculation of GHG impacts. But deforestation would also lead to emissions from: (1) the burning or decomposition of vegetation other than trees; (2) decomposition of necromass that accumulates with forest conversion; (3) loss of soil carbon as soil quality deteriorates after forest clearing (SGS 1998).[13]
2. *Focus on Carbon Dioxide.* The focus on carbon dioxide and the exclusion of other GHGs is another factor, albeit a less significant one. A number of GHGs are released through the burning of forests and through decay. Carbon dioxide emissions are far and away the most important GHG impact of deforestation, but trace amounts of GHGs such as methane and nitrous oxide are released as well (Fearnside 1992). While the exclusion of carbon pools other than trees and the focus on carbon dioxide are factors that bias calculation of GHG benefits downward, it is also notable that trying to measure these would present substantial technical challenges.
3. *No Logging in Baseline***.** A third reason to think that the PAP's baseline underestimates carbon benefits is the exclusion of the impact of selective logging—also referred to as forest degradation—in the baseline scenario. Forest degradation is eliminated in the project scenario. Thus, some carbon benefits are ignored since the difference in emissions levels due to forest degradation is not estimated. Selective logging leads to GHG emissions by three primary pathways: (1) tree matter that is unused may decay, thus causing emissions of carbon dioxide and methane; (2) trees and other vegetation damaged in the logging process may also decay, and; (3) emissions from soil disturbance and accelerated decomposition of detritus exposed

[13] Another category of impacts is wood products that would be removed from the forest in the baseline scenario but not the project scenario. The overall impact of this category is not clear. Most wood products will have long-lasting application where the wood decays at a slow rate (SGS 1998, p.46). The overall impact of wood products will depend on the rate of decay. If the rate of decay of the wood products is slow and biomass growth occurs at the site of wood product removal, this category would be a carbon sink. If the rate of decay is fast enough to outweigh whatever biomass growth occurs where the wood removal takes place, then the category would lead to net emissions compared to the baseline.

due to logging. GHG emissions by this process are mitigated in so far as logged wood leads to carbon storage through long-term use of wood products. Natural vegetation regrowth may also restore biomass density over time.[14]

Baseline Weaknesses

This assessment identifies two technical weaknesses that suggest that baseline deforestation rates may be too high: (1) the time period (1979-1992) used as the basis for extrapolation of baseline deforestation rates does not capture the recent trend toward decreasing deforestation rates; (2) the limitations of the data sets and means by which they were processed mean that forest fragments were missed (a problem since there were many more forest fragments in 1992, which suggests overestimation of deforestation). A third technical weakness is the lack of an empirical basis for the baseline for pastureland and secondary forestland.

1. *1979-1992 Time Frame as Empirical Basis.* The baseline's main technical weakness is the time period, 1979-1992, utilized as the empirical basis for the linear extrapolation of baseline deforestation rates. The OCIC did not have access to the recently completed comprehensive national study of change in land use and land cover over 1986-1997 (FONAFIFO 1998) when it was calculating the PAP baseline. As discussed in Section 9, the FONAFIFO study indicates a decrease in deforestation rates over the past decade to a level of about one percent per year with even lower rates (0.6%) in the boundary zones around protected areas. While the FONAFIFO study was made available only recently, earlier research (Lutz et al. 1993; Kishor and Constantino 1993; Solorzano et al. 1991) did presage the finding that deforestation has slowed recently. The importance of baseline deforestation rates to estimates of carbon benefits is demonstrated by the sensitivity analysis conducted in Section 11.
2. *Limitations of Remote Sensing Data and Methods of Analysis.* The discussion in Section 10.2. of the limitations of the OCIC's 1979 and 1992 remote sensing data sets

[14] Other proactive measures can be taken to mitigate the impact of selective logging but would not apply to the PAP baseline. Examples are (1) measures to reduce the impact of selective logging (e.g. on tress and other vegetation and soils); (2) use of residual biomass to reduce emissions in other areas (e.g. biofuels), and; (3) measures to assist in increasing in biomass density faster than natural recovery would allow in previously logged areas.

raises a technical problem with the empirical basis for the OCIC's baseline deforestation rates. The remote sensing technology and analytical methods used would likely be unable to detect smaller forest fragments, thus overestimating the amount of deforestation. This would not be a problem if forest fragmentation had remained constant, in which case there would not be differential impact in 1979 as opposed to 1992. However, since there was more forest fragmentation by 1992, the overestimation of deforestation is a relatively larger problem for that year (Sanchez-Azofeifa et al. (1998) mapped more than 9,000 forest islands with areas of less than 3 ha by 1992). As a result, deforestation rates in the 10-km boundary zone over the 1979-1992 time period, which are the empirical basis for the linear extrapolation, have likely been overestimated.

3. *Baseline for Natural Regeneration.* The baseline for pastureland and secondary forestland assumes that biomass growth and deforestation cancel each other out. The assumption is constant carbon content in the baseline. While biomass growth and deforestation are clearly countervailing forces, it is not obvious that their effects will be equal in magnitude. Credibility would be improved if an empirical basis for the baseline scenario in the case of natural regeneration.

Leakage

While many mitigation projects have simply ignored the issue of leakage, the OCIC addresses it for the PAP by initiating a parallel effort, the Private Forestry Project (PFP), to counteract the potential for negative leakage. The aim of the PFP is to increase the amount of forest cover on land outside of the PAP's boundaries. This approach offers conceptual simplicity in so far as it makes less important the difficult analytical issue of precisely quantifying the impact of leakage on overall project benefits. SGS still plans to consider leakage. Section 12 of this report discusses SGS's analysis of leakage.

While the PFP shows promise, a few questions remain about its effectiveness. Most problematic, the Finance Ministry suspended environmental service payments in July (Escofet 1998). Further the incentive and enforcement structure does not produce confidence in the long-term efficacy of the PFP. The PFP is supposed to require 20-year commitments of private landowners, but payments are made over five years (Subak 1998).[15] In the case of forest plantations, 50% of the total payment is made in the first year. The penalty for not maintaining the agreed upon land use is the return of the entire payment received (ibid.); in effect, there is no penalty. If a more lucrative land use should occur to the landowner, they can abandon the PFP without being any worse off than when they started.[16] Leakage will be further examined in the discussion of SGS's assessment of the project (Section 12.5.).

Additional Modeling Options

The linear extrapolation method used to predict baseline deforestation rates for the PAP is a relatively simple method, but it cannot be rejected on this basis. Increasingly sophisticated deforestation modeling techniques have been developed in recent years. Yet, these are more costly and do not eliminate uncertainty. Nonetheless, the OCIC and SGS should consider the application of other modeling approaches, especially given the large size of the project, in order to improve confidence in the baseline.[17]

Costa Rica has received an extraordinary amount of attention from scientific researchers who have developed a number of models that could be modified for use in constructing a baseline for the PAP. Persson and Munashinghe (1997) developed an economy-wide computable general equilibrium model for Costa Rica. Rosero-Bixby and Palloni (1997) estimated a spatial regression model for Costa Rica. Pontius et al. (1994) develop a relatively simple model called GEOMOD2 that they apply to Costa Rica with success. GEOMOD2 was able to predict deforestation over the period 1940-1983 using only data from 1940. A National Center for Ecological Analysis and Synthesis working group on carbon sequestration offers the most valuable opportunity for utilizing alternative models.

[15] While a landowner's commitment period is supposed to be 20 years, initial contracts have been for five years for plantations and ten years for sustainable forest management (Subak 1998).
[16] An exception is a case where abandoning the PFP would result in biodiversity losses in which case criminal charges may apply (Subak 1998, citing personal communication with Franz Tattenbach).
[17] Indeed, SGS has recommended the development of a more advanced extrapolation technique, one that is based on three points rather than two and thus need not be linear.

The working group has developed a dynamic optimization model of land use and land cover change for Costa Rica (Kerr et al. 1999a, 1999b). The model is of the behavioral type. It will emulate the decision-making process for land managers who seek to maximize their land's value (e.g. maximize profits). The model's parameters are empirically estimated from land use and land cover, environmental, geographic and socioeconomic data.

11. Sensitivity Analysis

In order to investigate the significance of assumptions about future deforestation, LBNL conducted an analysis of the sensitivity of estimated carbon savings to changes in baseline deforestation rates. LBNL re-evaluated the carbon savings expected due to the PAP using three different sets of baseline deforestation rates that were chosen to represent high, medium and low levels of deforestation. The medium scenario replicates the OCIC's methodology but updates the empirical foundation for the calculation by using the FONAFIFO 1986-1997 data on deforestation in the 10km boundary zones around protected areas. The medium scenario is based on a baseline deforestation rate of 0.38%/year, which can be compared to the OCIC's baseline rate of 0.85%/year. The low deforestation scenario (0.056%/year) assumes that baseline deforestation rates observed inside the protected areas over the period 1986-1997 continue in the future. The high deforestation scenario assumes a rate of 2.15%/year and is based on the rates of deforestation observed in the boundary zones around the protected areas from 1979-1986.

The motivation for developing these different scenarios is to see how carbon savings vary when different assumptions are made about how the future will unfold. The estimated carbon savings vary widely when different deforestation rates are used as the empirical basis for baseline deforestation rates. As a basis for comparison, the OCIC/SGS scenario is included along with the low, medium, and high deforestation scenarios in Table 6.

Table 6. Sensitivity of Carbon Savings to Changes in Baseline Deforestation Rates

Scenario (Empirical Basis for Baseline Deforestation Rates)	Baseline Deforestation Rate[1]	Carbon Savings due to Conservation[2]	Total Carbon Savings
OCIC/SGS (1979-1992 deforestation rates in 10 km boundary zone outside of protected areas)	0.849%	11.7 Mt	15.7 Mt
High Deforestation (1979-1986 deforestation rates in 10 km boundary zone outside of protected areas)	2.15%	25.9 Mt	29.9 Mt
Medium Deforestation (1986-1997 deforestation rates in 10 km boundary zone outside of protected areas)	0.376%	4.97 Mt	8.94 Mt
Low Deforestation (1986-1997 deforestation rates inside protected areas)	0.056%[3]	0.67 Mt	4.64 Mt

Sources: FONAFIFO (1998), SGS (1998).

[1] This is a weighted average. The rate was calculated by (1) applying the OCIC baseline methodology to the raw deforestation rates empirical data (e.g. boundary zone deforestation rate multiplied by the land tenure risk factor) and (2) multiplying these results for each protected area by the fraction of primary forest in that protected area to find a weighted average for the project as a whole.

[2] Carbon savings in this column are those due to forest conservation only, not natural regeneration.

[3] Note that this scenario departs from the OCIC approach of using deforestation rates observed in a 10km boundary zone surrounding protected areas as the basis for estimating baseline deforestation rates. Instead, this scenario assumes that baseline deforestation rates will equal deforestation rates observed inside protected areas over the last decade (no land tenure risk factor is applied).

Figures 4 and 5 present this information in graphical form to further illuminate the relationships and assumptions being examined. Figure 4 shows historical rates of deforestation inside protected areas and in the boundary zones surrounding them as well as the baseline deforestation rates for the OCIC/SGS scenario and the three additional scenarios constructed here. Figure 5 demonstrates graphically how carbon savings change with the different imputed baseline deforestation rates associated with the different scenarios.

Figure 4. Deforestation Rates:
Historical and Four Possible Baseline Scenarios

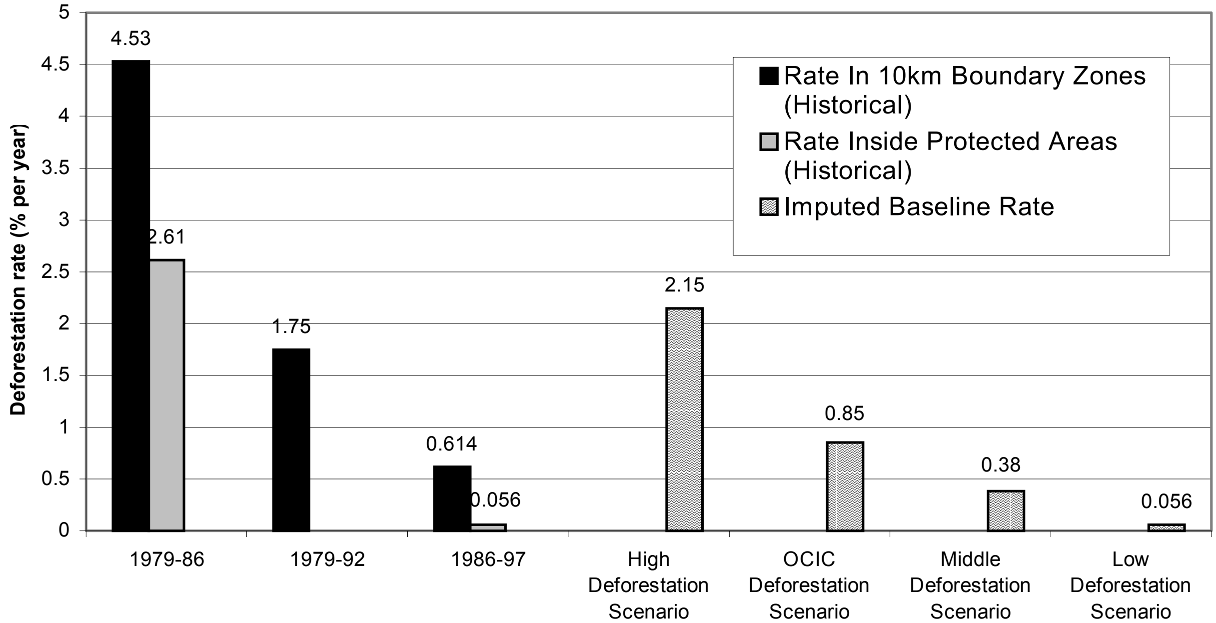
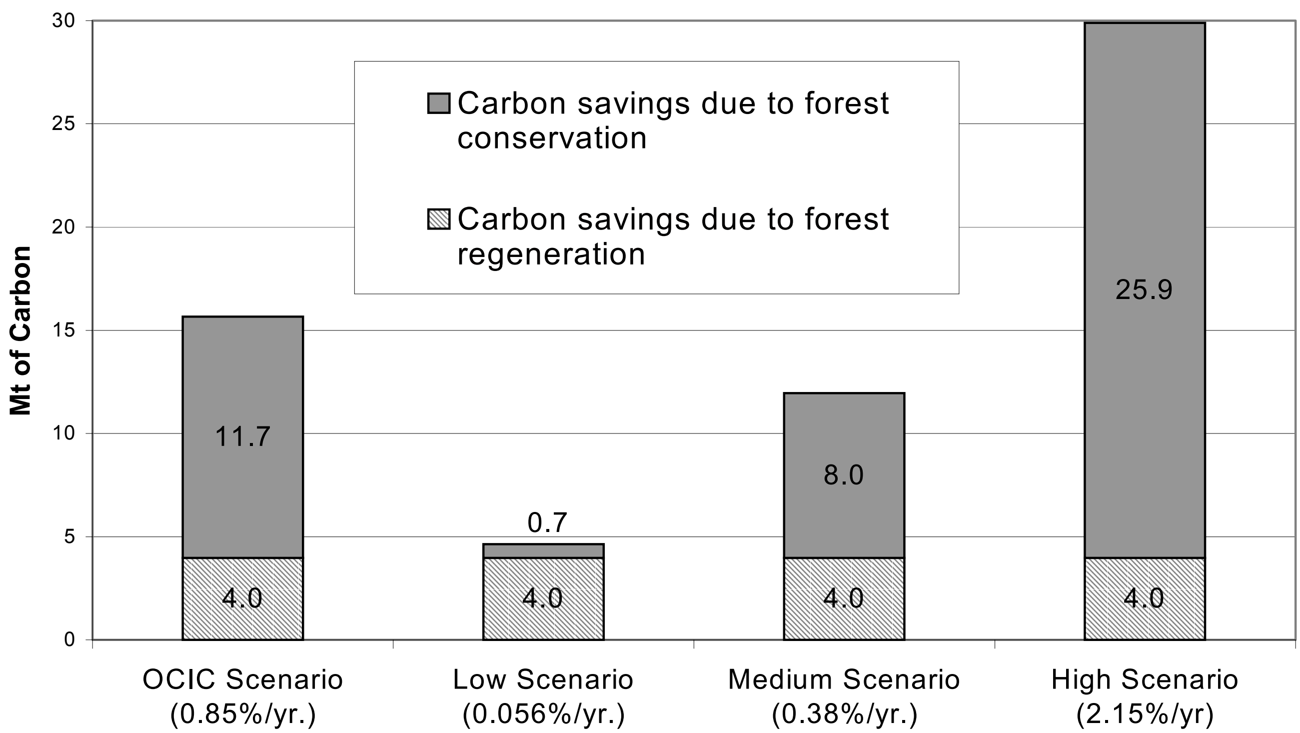


Figure 5. Sensitivity of Carbon Savings to Changes in Baseline Deforestation Rates



Below is a hypothetical discussion of the events that might actually lead to the rates of deforestation contemplated in the various scenarios analyzed in this section. Each of the scenarios can be thought of as identifying, in a general sense, ways that the future might unfold. The discussion is based on the question: Assuming that the PAP did not go forward, under what circumstances might each of these scenarios occur? The hypothetical nature of the scenarios that are sketched should be stressed. The intent is only to demonstrate in a very simple way that different chains of events could affect deforestation rates in different ways. Conclusions should not be drawn about likely future drivers of deforestation.

OCIC/SGS Scenario (0.85%/year). The OCIC uses boundary zone deforestation rates from 1979-1992 to estimate baseline deforestation rates. This scenario results in about 15.7 Mt of carbon saved. For this scenario to be accurate, the slowing of deforestation that was observed over the past decade would have to be reversed. A Pan-American recession that causes a recession in Costa Rica might cause such an increase in deforestation rates. In hard economic times environmental concerns are sometimes dismissed as luxuries not high on the list of priorities. Costa Rica would feel less international pressure to protect their forests, and the countries' environmental groups might find it difficult to have their voices heard. Meanwhile, landowners would feel more justified than before exploiting the natural capital, e.g. forests, on their land. The government would have even less money than before to enforce forest protection afforded under the law or to offer incentives for forest protection to private landowners.

High Deforestation Scenario (2.15%/year). Such a scenario would mean a sharp reversal of the slower deforestation rates that have been observed over the past decade. This scenario seems unlikely given the recent trends and Costa Rican Government commitments to sustainable developments. Nonetheless, history is replete with examples of unexpected events. One potential driving force of such a scenario would be catastrophic economic decline in Costa Rica or in one of its neighbors. Such an economic collapse could result from some combination of armed conflict, a public health crisis, and natural catastrophes. Forest clearing carried out by poor landless migrants has not been a significant source of deforestation in Costa Rica in recent years (Lutz and Daly 1991; Lutz et al. 1993). However, the emergence of extreme poverty in Costa Rica or one of its neighbors could lead to an explosion of deforestation by desperate people. The largest land tenure type within the PAP is national reserve land (54% of the land). This land has not yet been surveyed or registered and is subject to public claim.

Medium Deforestation Scenario (0.376%). This scenario would occur if landowners within protected areas behave as landowners in the 10km boundary zones have behaved over the past decade. In essence, this scenario accepts the OCIC's assumptions vis-à-vis baseline deforestation rates and updates the empirical basis for these using recently compiled FONAFIFO data. The baseline deforestation rates inside the protected areas would rise substantially over those observed in the last decade under this scenario.

The following series of events could lead to future deforestation rates similar to those predicted by scenario one. The national government does not allocate funds to consolidate land within protected areas. Furthermore, the government does not try or is not able to circumvent, either through policy or political pressure, the Constitutional ruling prohibiting controls on land use in the absence of full compensation. No longer constrained by the government, some landowners choose to permanently clear the land of forest.

Low Deforestation Scenario (0.056%/year).. If the very low rates of deforestation observed in the protected areas from 1986-1997 continue in the future, the PAP would result in about 4.6 Mt of carbon saved. The values and beliefs of the Costa Rican population have increasingly shifted from the view that forests represent an obstacle to development to recognition that natural forests themselves have important value. Beef exports are no longer a source of great wealth. It may be that the economic and political reality on the ground has finally caught up to the rhetoric of environmental protection heard from Costa Rican leaders. The economic, political, and cultural landscape in Costa Rica may have fundamentally shifted such that deforestation of any importance within protected areas will not be tolerated.

There are three means the national government might be able to use to stop deforestation in the protected areas despite the Constitutional ruling: (1) political pressure; (2) the power to deny permits under Forestry Law No. 7575, and; (3) unanticipated funding sources that may materialize in the future. Perhaps a combination of unofficial pressure and denial of permits could keep deforestation rates at the low level observed in the last decade, at least until the Costa Rican Government's budgetary circumstances have changed and it can afford to purchase privately-held land in protected areas.

There is some reason to believe that the government pressure on landowners to forestall deforestation in protected areas could be effective, at least in the short term. Anecdotal evidence suggests that political pressure, even in the absence of cash payments to private landholders, has in the past held off those who would clear forests in protected areas. For example, the manager of the Manuel Antonio National Park, Ricardo Rodriguez, explains that he has so far been able to keep private land owners from exploiting forested land they own in the park: "They knock on our door everyday and say, 'hey guys, we need the money, because that's our land.' They try to tell us, 'we need land for our cattle. We're going to cut it down if you don't pay us.' We say, 'okay, we don't have the money, we're looking for the money. Take it easy," (Burnett 1998).

Another option the national government has is to use Forestry Law No. 7575 of 1995 to forestall deforestation. The law requires landowners to acquire permits for forest felling, and it allows deforestation only in very limited circumstances. The law states that, "The forestry administration can permit deforestation only for the following: (a) to build houses, offices, and etc. that are dedicated to ecotourism or to improve farm management on private lands inside of natural forests; (b) to carry out infrastructure projects (private or official) that are important for the country; (c) to cut trees due to human risk or scientific interest; (d) to prevent forest fires, natural hazards or other consequences." The penalty for tree cutting without a permit is six months to three years in jail.

The law seems to provide the forestry authorities substantial discretion in deciding when to issue the permits needed for legal forest clearing. There certainly could be difficulties in enforcing the permit requirement, especially given the Costa Rican Government's budgetary limitations. Illegal deforestation has been a problem in the past.   Moreover, if the government denies all permit requests that fall within protected areas, the law might be challenged and eventually overturned. However, even if the use of the law was found to be unconstitutional and some deforestation was to occur without permits, some deforestation would have been avoided. Some time would have been gained and the government might be able to raise funds to pay for consolidation of the protected areas.

12. Discussion of SGS' Certification of One Million Tonnes of Carbon for Sale

12.1. Overview of the SGS Report

In August of 1998, SGS International Certification Services Ltd., an independent firm retained by the Government of Costa Rica, issued a report that certifies the overall design of the PAP subject to the implementation of eight additional corrective actions.   The SGS report also estimates quantitatively the carbon savings that are anticipated due to the consolidation in April 1998 of the first 30,000 of the 530,000 hectares of land included in the PAP. Carbon saving estimates are based on a quantitative assessment of the project baseline, including risks and uncertainties associated with the baseline, and are referred to as a "Schedule of Projected Emissions Reductions."   SGS's Schedule of Projected Emissions Reductions is also contingent upon implementation of the correction actions SGS has recommended.

12.2. Summary Technical Review

SGS' certification report covers an array of potential uncertainties that range from political and economic risks to natural catastrophes such as fires. The SGS approach offers a valuable means for approaching questions of uncertainty. The approach recognizes that uncertainty is inevitable and need not be paralyzing. Until risks and uncertainties vis-à-vis the PAP are further investigated, SGS has recommended that almost 40% of the carbon offsets anticipated due to consolidation of the first tranche of land be set aside in a buffer.

Viewed in the aggregate, this is a large buffer. However, in the key area of baseline deforestation rates, SGS reaches overly optimistic conclusions. SGS suggests that the OCIC's baseline deforestation rates are conservative, e.g. are unlikely to overestimate the amount of future deforestation without the PAP, despite the slowing of deforestation in recent years and the time period (1979-1992) used as an empirical basis. Furthermore, SGS's assessment underestimates the degree of uncertainty associated with predicting baseline deforestation rates. The result is a 98% confidence interval that is too narrow in light of the difficulty of predicting deforestation rates over long periods of time.

It may be that the specific quantities of offsets contributed to the buffer to cover uncertainty about baseline deforestation rates should be viewed in conjunction with the buffer as a whole rather than in isolation. It may be that risks can be pooled across categories. But this argument has not yet been developed and put forth. The last part of this section will review SGS's assessment of leakage, e.g. indirect or offsite impacts due to the project.

12.3. SGS's Assessment of Baseline Deforestation Rates

SGS recognizes the technical problems with the 1979 and 1992 data sets and further suggests that two data points are inadequate for an accurate representation of deforestation trends. SGS recommends additional data collection and development of a more sophisticated extrapolation approach to predict baseline deforestation rates. Despite concerns about the 1979 and 1992 data sets and the OCIC's simple linear extrapolation technique, SGS repeatedly refers to the OCIC's baseline deforestation rates as either conservative or very conservative, e.g. are likely to underestimate the deforestation rates that would occur in the absence of the PAP. The SGS report claims that even though trend in deforestation defined by the 1979 and 1992 data points is likely inaccurate, since the baseline deforestation rates used by the OCIC are so conservative: "it is unlikely that increasing the accuracy of the measurements will result in substantially lower rates," (SGS 1998, p.130).

Neither SGS nor the OCIC had access to the FONAFIFO data analyzed in this report. Nonetheless, there were indications in the literature that deforestation was slowing down (Lutz et al. 1993; Kishor and Constantino 1993; Solorzano et al. 1991). Indeed, Appendix V suggests that SGS was not completely unaware of the changing trends. The SGS report notes that, "a decrease in deforestation rates is observed during the last decade," (p.129). In figure 1, the report further hints at the conclusion that using the 1979-1992 10km boundary zone trend as an empirical basis may overestimate baseline deforestation rates. The figure shows what happens when a hypothetical third data point is added between the 1979 and 1992 data points. Based on the positioning of the added data point, it seems that SGS anticipates a future finding of a reduced deforestation rate in recent years. The shape of the trendline that results from the hypothetically added data point suggests decreasing deforestation rates.[18]

SGS cites two studies, one by the FAO (United Nations Food and Agricultural Organization) and one by CIEDES (Sustainable Development Research Center, University of Costa Rica) to support the conclusion that the OCIC's baseline deforestation rates are conservative. Neither study is listed among the SGS report's references.

On page 27, the SGS report states that the FAO (1990) found a 3% rate of deforestation over the previous 20 years. This seems to refer to FAO's 1993 report *Forest Resources Assessment 1990: tropical resources* that covered the time period 1981-1990 and an earlier report that covered the previous decade. The FAO provides a global overview of

[18] The SGS report suggests that adding data from another point in time, "does not change the angle but the shape of the trend line," (p.129). In fact, as drawn in figure one, the slope of the new trendline does change and will only be parallel to the original trendline at one point.

tropical deforestation. However, in striving to build a picture of such a large scope, the FAO must sometimes use data that is not reliable. The sampling and stratification techniques used by the FAO have been criticized as inaccurate (Sanchez et al. 1997).

The findings of country specific studies are generally more reliable, especially in the case of Costa Rica. The WRI/TSC (Solorzano et al. 1991) study discussed in the Section 8.1.1. of this report found deforestation rates decreasing from 48,800 hectares per year for 1966-1973 to 31,800 hectares per year for 1973-1989. The study estimated that forest cover accounted for 58.5% of national territory in 1966 and 42.9% in 1989. For 1989, when the percentage rate of deforestation estimated by the WRI/TSC study would be at its highest level because the forest cover would be at its lowest level, 31,800 hectares per year amounts to a 1.5% annual deforestation rate.

The second study SGS cites is described as a CIEDES report that found a rate of deforestation of 4% per year over the period 1986-1991. Apparently, this is a reference to Dr. Arturo Sanchez-Azofeifa's doctoral dissertation, which analyzed deforestation over the time period 1986-1991. Dr. Sanchez's dissertation found a deforestation rate of 45,000 hectares per year and forest cover of 32% in 1986 and 29% in 1991 (Sanchez 1996). However, the area studied did not cover the entire country. Satellite images covered 93% of the country, and cloud cover obscured 17% of these images. Areas where most deforestation was occurring were included in the study, but not large areas of forestland in the Osa Penisula and in the north of Costa Rica near the Caribbean coast. As a result, the 45,000 hectares per year rate of deforestation can be considered a national figure, while the forest cover estimates substantially underestimate total forest cover.

SGS seems to have mistakenly treated Dr. Sanchez's dissertation's findings on forest cover as national estimates. When a 45,000 hectares per year rate of deforestation is viewed in the context of 29% national forest cover, the percentage rate of annual deforestation amounts to 3.1%. This is still somewhat smaller than the 4% rate of deforestation that SGS reports was found by the CIEDES study. When the WRI/TSC study's estimate of 42.9% national forest cover in 1989 is used, the rate of deforestation found by Dr. Sanchez, e.g. 45,000 hectares per year, translates to a rate of about 2.1% annually.

The WRI/TSC study's findings have been corroborated by other research. The recently completed FONAFIFO study found 40% forest cover for the nation in 1997 and a rate of deforestation of 1% annually. Other studies—Lutz et al. (1993) and Kishor and Constantino (1993)—have also found deforestation rates to be decreasing and much lower than the 3% and 4% annual rates cited in the SGS report.

Analysis of the FONAFIFO data with respect to the four protected areas included in the first tranche further suggests that the OCIC's baseline deforestation rates seem more likely to overestimate future deforestation than underestimate it. The same four categories of deforestation rates that were analyzed for the PAP as a whole in Section 11 are analyzed for the first tranche in Table 7 below.

Table 7. First Tranche Baseline Deforestation Rates with Different Empirical Bases

Empirical Basis for Imputed Baseline Deforestation Rates	Historical* Deforestation Rate	Imputed Baseline Deforestation Rate**
1979-1992 rates in 10 km boundary zone outside of protected areas (OCIC/SGS)	1.47%	1.09%
1979-1986 deforestation rates in 10 km boundary zone outside of protected areas	3.41%	2.42%
1986-1997 deforestation rates in 10 km boundary zone outside of protected areas	0.476%	0.396%
1986-1997 deforestation rates inside protected areas	0.245%	0.245%***

Sources: FONAFIFO (1998), SGS (1998).

* The historical rate is the average annual deforestation rate over the given time period among the four protected areas in the first tranche weighted according to area of primary forest.

** The imputed baseline deforestation rate uses the historical rate given as the empirical input to the OCIC's baseline methodology, e.g. the OCIC's land tenure discount factors are applied to the deforestation rate for land that is not privately owned.

***Note that this category departs from the OCIC approach of using deforestation rates observed in a 10km boundary zone surrounding protected areas as the basis for estimating future (baseline) deforestation rates. Thus, it does not make sense to apply the OCIC's land tenure risk factors to this rate. Instead, the raw historical rate is listed.

Table 7 shows that deforestation rates in the 10km boundary zones outside of the protected areas dropped by about 1/3 in the 1986-1997 time period when compared to the 1979-1992 time period.

The SGS report's discussion of future trends effectively covers the wide range of driving forces of deforestation. The important point is made that expansion of pasture for cattle will not likely be the key driving force in the future that it has been in the past. The discussion of future trends does not address the question of whether the slowdown in deforestation will continue is obviously not addressed.

12.4. SGS's Methodological Approach to and Assessment of Risk and Uncertainty

12.4.1. Risk Quantification and the Buffer

SGS carries out a risk and uncertainty assessment to account for risks and uncertainties that might lead to lower than expected carbon savings. Three categories are considered: (1) uncertainty with respect to the baseline; (2) scientific uncertainties related to methodologies used, such as standard errors associated with biomass estimates, and; (3) project risks, such as natural disasters. SGS' risk quantification mechanism seeks to analyze all potential risks and uncertainties to determine the number of carbon offsets out of the anticipated total (the best estimate) that should be retained in a reserve fund of carbon offsets that is referred to as a buffer. The carbon offsets in the buffer can be accessed if something happens to reduce the number of offsets realized by the project. For example, SGS analyzes the risk of a landslide and determines that 28,000 offsets from the first tranche should be held in reserve to account for the possibility of a landslide.

SGS' risk quantification mechanism employs an expected value approach. The probability of an event is multiplied by its magnitude to determine its expected effect. In SGS's parlance, the quantified risk is the product of likelihood (e.g. probability) and significance (e.g. magnitude of impact). The level of risk is subject to some reduction if project developers have put in place risk management systems. The risk quantification approach can be represented as:

$$\mathbf{R = L \times S \times (1 - (P \times MS)/20)} \quad \text{(2)}$$[19]

Where:

R = the level of quantified risk associated with a potential event

L = the likelihood of an event occurring

S = the significance of an event (worst case)

P = the technical adequacy of risk response or risk management procedures

MS = the adequacy of risk management systems

SGS's assessment of the probabilities of risks, magnitude of impacts, and risk management systems in place is based on a combination of empirical scientific studies and professional judgement. As SGS explains, "in the absence of statistically valid methods, estimated confidence intervals will be used" (1998, p.69).

The quantified risks for the various risks and uncertainties are added together to determine the overall size of the buffer. Based on this approach, SGS asserts that no more carbon offsets will be sold than the project can produce and that carbon offsets authorized for sale are, "98% implementation risk and uncertainty free," (1998, p.68).

The size of the buffer can be adjusted over time as new information comes to light. Thus, a portion of the offsets from the first tranche is to be held in the buffer to cover uncertainty about the dynamics of forest regeneration on degraded pastureland. As the dynamics are further studied and better understood, and if it found that the regeneration of biomass on pasture land is proceeding as anticipated, the offsets placed in the buffer to cover this risk can be removed from the buffer and sold.

12.4.2. Assessment of Risk and Uncertainty

SGS' risk and uncertainty assessment indicates that 670,000 tonnes of the 1.7 Mt of carbon in the first tranche should be held in the buffer in case ex-post analysis indicates some of the anticipated offsets fail to be produced. In its assessment of uncertainty regarding the baseline, SGS recognizes some risk that the OCIC's baseline deforestation rates overestimates future deforestation. For tranche one, the OCIC's baseline deforestation rates suggest 612,000 tonnes of carbon savings due to primary forest conservation. SGS recommends that 98,000 (16% of 612,000) of these 612,000 tonnes of carbon be held in reserve in case future assessments indicate the OCIC's initial baseline deforestation rates were too high.

[19] SGS notes that "the product P x MS is divided by 20 because the maximum score for P and MS are 4 and

This assessment of uncertainty with respect to baseline deforestation rates was reached as follows. SGS predicts that the OCIC's baseline deforestation rates have overestimated future deforestation rates by no more than 20%. A 100% likelihood of incorrectly specified baseline deforestation rates is recognized.[20] Thus, before risk management has been considered, SGS's assessment of the likelihood and significance—the probability and magnitude of the error in expected value terms—indicates an expected error of 20% (100% x 20%).

Recall that some reduction in the size of the buffer needed to cover a given risk may occur if the OCIC has taken risk management precautions. SGS reduces the magnitude of the expected error with respect to baseline deforestation rates by 1/5 in order to account for the risk management systems and procedures the report says are in place. Under risk management procedures and systems, the following two-part justification is given for reducing the risk of an error in baseline deforestation rates:

> "[1] Currently, no action has been undertaken by OCIC to identify or improve the level of accuracy of the estimates of the key parameters. However there is scientific justification behind each estimate and the satellite image data has been prepared under a quality management system (ISO 9000)… [2] There is currently no documented system describing attempts to improve the accuracy of the estimates of key variables and audit progress against those targets. There is, however, a process of peer review, whereby the scientific methodology has been reviewed by a panel of experts who have commented on the methodology and figures utilized. The outcome of that review was unanimously positive," (p.70)

This discussion seems to be more relevant to the size of the expected error in estimating baseline deforestation rates than risk management procedures or systems. The peer review process that is mentioned could be better referenced and the 1/5 reduction could be more robustly justified.

5 respectively, and their product is 20," p.67.

[20] This 100% probability of error illustrates the central role of judgement in estimating the appropriate number of offsets to retain in the buffer in many cases. If there is a 100% chance of error, then the baseline should be adjusted. It seems that a judgement was made vis-à-vis the appropriate number of offsets for the buffer and the specific values in the calculation were chosen to achieve this.

After SGS reduces its estimate of the potential error of baseline deforestation rates by 1/5, the quantified risk rating falls to 16% (4/5 of 20%). In other words, SGS asserts that there is only a 2% chance that the carbon savings for first tranche due to primary forest protection will be less than 514,000 tonnes, e.g. 16% lower than their estimate of 612,000 tonnes, or higher than 612,000 tonnes. There would seem to be a much greater possibility that carbon saving will in fact be lower, especially in light of evidence that deforestation has been slowing in Costa Rica. A confidence interval of 100,000 tonnes of carbon, e.g. between about 500,000 and 600,000 tonnes, is likely too small.

The SGS report states on more than one occasion that estimated carbon savings are not sensitive to changes in baseline deforestation rates. The specific claim is made that: "increasing the error in the deforestation rate from 10% to 20% results in the loss of a further 1.5% of offsets," (1998, p.69). The assertion that estimated carbon savings are relatively insensitive to baseline deforestation rates seems overstated. The magnitude of the potential error in baseline deforestation rates is important. Of the 1.7 Mt of carbon savings estimated before risks are taken into account, about 612,000 tonnes are due to protection of primary forest.[21] If the maximum error is assumed to be 10% (really 8% after the 1/5 reduction for risk management), then about 49,000 tonnes of the carbon savings estimated due to forest protection would need to be kept in reserve. If the maximum magnitude of the error were assumed to be 20%, then about 98,000 tonnes of carbon would be required for the reserve fund. Thus, the difference between an error of 10% and 20% would be 49,000 tonnes, which is 2.9% of 1.7 Mt. This is larger than the 1.5% figure reported by SGS.

The sensitivity of carbon savings associated with first tranche to changes in deforestation rates is further illuminated in Table 8.

[21] Recall that for the project as a whole forest conservation accounts for roughly three quarters of carbon offsets and that the baseline for forest conservation relies heavily on baseline deforestation rates.

Table 8. Sensitivity of First Tranche Carbon Savings to Changes in Baseline Deforestation Rates

Scenario (Empirical Basis for Baseline Deforestation Rates)	**Baseline Deforestation Rate**[1]	**Carbon Savings -Conservation (tonnes)**[2]	**Total Carbon Savings**
OCIC/SGS (1979-1992 deforestation rates in 10 km boundary zone outside protected areas)	1.09%	612,000	1.69 Mt
High Deforestation (1979-1986 deforestation rates in 10 km boundary zone outside of protected areas)	2.42%	1.19 million	2.27 Mt
Medium Deforestation (1986-1997 deforestation rates in 10 km boundary zone outside of protected areas)	0.396%	239,000	1.32 Mt
Low Deforestation (1986-1997 deforestation rates inside protected areas)	0.245%[3]	150,000	1.23 Mt

Sources: FONAFIFO (1998), SGS (1998).

[1] This rate was calculated by (1) applying the OCIC baseline methodology to the raw deforestation rates empirical data and (2) finding the average baseline deforestation rate for the four protected areas in the first tranche weighted according to area of primary forest.

[2] Carbon savings in this column are those due forest conservation. Carbon savings are estimated before SGS's risk and uncertainty quantification mechanism has been applied.

[3] Note that this scenario departs from the OCIC approach of using deforestation rates observed in a 10km boundary zone surrounding protected areas as the basis for estimating baseline deforestation rates. Instead, this scenario assumes that baseline deforestation rates will equal deforestation rates observed inside protected areas over the last decade (no land tenure risk factor is applied).

This sensitivity analysis suggests that SGS's 98% confidence interval for carbon savings due to primary forest protection in the first tranche is too small. Predicting baseline deforestation rates over a 20 year time period is a difficult endeavor. Deforestation rates almost inevitably change over time.

Assessment of uncertainty with respect to baseline deforestation rates is an area where professional judgement must be exercised. The project's credibility would be enhanced by a more modest assessment of the level of certainty with which the future of deforestation can be predicted. As indicated in the summary comments, SGS may wish to develop the idea that risk can be pooled among the various risks and uncertainties that have been identified. While the 98% confidence interval for uncertainty with respect to the baseline seems too small, the overall size of the buffer is rather large at 40% of the total anticipated offsets. The 600,000 carbon offsets retained in the buffer would be sufficient to cover an ex-post shortfall in carbon offsets even in the low deforestation scenario described above (without other major shortfalls).

12.5. Leakage: SGS's Treatment of Off-Site GHG Impacts

The SGS reports' assessment considers the possibility of leakage for the project as a whole and quantifies the risk for the first Tranche. SGS concludes that the project as a whole may motivate the displacement of some deforestation pressure, but that this will be a small fraction of the direct GHG impacts due primarily to the PFP (Private Forestry Project, outlined in Section 10.3.), which offers environmental service payments to private land holders. No offsets from the first Tranche are added to the buffer to account for the possibility of leakage, but the SGS report notes that future Tranches will require the retention of some carbon offsets in the buffer to cover the potential of leakage.

A parallel program designed specifically to address deforestation, such as the PFP, offers conceptual simplicity for addressing leakage. Of course, payments will have to be resumed for the PFP to work as planned. Further, if penalties for withdrawal from the program were made more substantial, confidence in the long-term efficacy of the program could be increased. Even without payments, the assessment of no risk of leakage is defensible for the first Tranche because it is so small (30,000 hectares compared to 530,000 for the project) and a survey of the landowners indicates that they are not eager to clear forest once they have been bought out. Further, SGS plans to monitor the impacts of former owners of land within the PAP. It is notable that the former PAP landowners are only one potential source of leakage. Demand for agricultural products (food and timber) that would have been met by activity within the PAP will need to be satisfied somehow. Even if supply side measures are effective within Costa Rica, it is possible that deforestation pressure could be shifted to areas outside the country.

Leakage is a very complex topic. Typically, many different effects, both positive and negative, can be identified. To estimate the cumulative effect of the various indirect impacts is analytically challenging. Ultimately, the best way to address leakage is to design a project such that the major sources of negative leakage are addressed. The PFP is an example of such a program.

That Costa Rica's Financy Ministry suspended the PFP's environmental service payments is problematic. The PFP is the linchpin of SGS's assessment. Nonetheless, SGS's recommendation of a large buffer (40% of total first Tranche offsets) provides a measure of comfort. Still, if the PFP fails to be implemented as planned, a new assessment of the potential for leakage will be required.

SGS's assessment methodology covers the four types of off-site impacts that are typically recognized: (1) activity shifting; (2) outsourcing; (3) market effects; (4) life cycle effects. The SGS report divides these four off-site effects into two categories: slippage, comprised of items one and two from the list above, and leakage, which includes items three and four.[22] The specifics of SGS's risk quantification assessment with respect to slippage and leakage are discussed below.

[22] Some confusion arises with respect to SGS's definition of leakage and slippage due to differences between the definitions in the text and Appendix II of SGS's 1998 report. The text (pp.82-84) indicates that leakage occurs due to, "relocation of land use change activities to areas outside the project," (p.82). The text further says that slippage results when, "injection of capital into communities alters their lifestyles," (p.83). These definitions are reversed in Appendix II, which gives a general discussion of SGS's approach to off-site impacts. Therein, slippage is defined as the, "geographic relocation of GHG emission causing activities as a result of the project's implementation," (activity shifting and outsourcing) and leakage is defined as, "GHG emissions indirectly incentivized by the project," (market and life cycle effects) (p.111). The definitions employed in Appendix II the SGS report are used herein. The discussion of slippage and leakage in Section 6.1. (pp.32-33) indicates that the definitions in the Appendix are the intended ones.

Slippage

SGS's analysis of slippage focuses on activity shifting (subsistence or commercial). Outsourcing is not an issue for the PAP. SGS focuses on the possibility that agricultural activities will shift to areas outside the project's boundaries. The SGS report lists three reasons to support its assessment that there is no possibility that the shifting of activities to satisfy subsistence demand will cause slippage in the case of the first tranche.

(1) The primary reason is the existence of the PFP. It is noted that a priority for the PFP is the 10 km boundary zone around protected areas where SGS asserts that landowners bought out by the PAP are most likely purchase land.

(2) The second general point that SGS makes starts with the observation that most landowners within the PAP have not relied on this land for income since the constitutional ruling limiting the government's power to control land use on lands it has not paid for was only decided recently. Thus, SGS concludes, it is doubtful that landowners will use revenue from selling land within a protected area to buy land for agricultural activities. The problem with this point is that it can also be used to argue that the risk of deforestation inside the protected areas is overstated. If landowners have not relied on the land for income in the past and are not likely to undertake land use change activities outside the boundaries of the PAP, this seems to make it more difficult to argue that the landowners are a deforestation threat inside the PAP.

(3) The third point SGS makes in its assessment of the potential for leakage is specific to the first tranche of offsets. The report notes that only one parcel of land in the first Tranche is privately held: "the acquisition programme of this year includes only one private owner – a bank, holding the land after foreclosing on a loan. The bank will not use the revenues derived from the sale of the land to the State to purchase new areas and undertake land use change activities," (p.82). It would be interesting to know what the bank would do with the land in the baseline scenario.

The SGS report seems to focus on one side of the equation in analyzing the possibility for activity shifting. Former landowners within the PAP are not the only potential causes of leakage. It is also important to consider the underlying agricultural demand that exists and is a driver of deforestation in the baseline scenario. While subsistence demand has not played a major role in Costa Rican deforestation (Lutz et al. 1993), the pursuit of commercial profit has been a key driving force in the past (Daly and Lutz 1991). The PFP may mitigate logging pressure as it encourages the development of wood plantations, thereby increasing supply. It is not clear how demand for food (and associated demand for agricultural land) that would be satisfied by land within PAP in the baseline scenario will otherwise be satisfied.

Leakage

In its analysis of leakage, SGS focuses on the project's market effects. More specifically, the report analyzes what landowners will do with proceeds from sale of land within protected areas. It is noted that a small farmer may receive enough money to buy an air conditioner, but, on the other hand, another small farmer may be able to afford to replace his vehicle with a more energy efficient version. The report also suggests that wealthy landowners will not cause leakage because they already own vehicles, air conditioners and other items. The experience in industrialized countries has been that over the long-run gains in income can overwhelm energy efficiency improvements with the net effect being increased GHG emissions, especially if energy prices are low (Schipper and Meyers 1992). Regardless, these income impacts are likely to be much smaller than the direct impacts of the project.

Positive Leakage

The SGS report observes a potential for positive indirect impacts due to the PAP. In addition to the PFP, "leakage will be further mitigated by some of the NGO's [non-government organizations] which will sell their lands back to the government through the PAP (approximately 46000 ha or 9% of the PAP lands belong to NGOs) and a large proportion of the funds raised through these sales will be used to catalyze positive environmental activities elsewhere in Costa Rica," (p.32). This argument seems reasonable, but recall that within the PAP NGO's are assumed to be agents of deforestation. A relatively low deforestation rate is assigned to their lands (3/7's the level of private land). It does seems possible the NGO's could be agents of deforestation inside and positive catalysts outside. This would seem to require that NGO's cause some deforestation, but less than the baseline level for the "average" piece of land. However plausible the potential for positive leakage, the magnitude of its impact will not be large.

CONCLUSION

13. The Challenges of Constructing a Baseline

13.1. Summary of Case Study Findings

The PAP in many senses advances the state of the art for CDM-type forestry projects. Substantial resources have been invested in developing carbon savings estimates grounded in scientific rigor. A third-party evaluator has been retained to monitor, evaluate and certify the project's design and performance. Moreover, this case study identifies four ways that the design of the baseline and analysis of emission reductions protects against overestimation of carbon savings:

(1) carbon pools other than trees are not included in the estimation of carbon savings;
(2) GHG flows other than carbon dioxide are excluded;
(3) emissions due to selective logging are not considered in the baseline scenario;
(4) SGS's recommendation that some offsets be retained in a buffer to account for uncertainty with respect to the baseline.

This report also recommends three ways to enhance confidence in estimates of carbon savings due to the PAP:

(1) Baseline deforestation rates should be updated using the newly available FONAFIFO data on national forest cover for 1986 and 1997;
(2) More sophisticated land cover, land use change modeling methods could be applied to the task of predicting baseline deforestation, and;
(3) A stronger analytical and empirical basis could be developed for the assumption of constant carbon content in the baseline scenario for secondary forest and pasture (which is based on the idea that the countervailing forces of deforestation and biomass growth will equal each other).

The FONAFIFO (1998) study confirms other research indicating that Costa Rican deforestation had slowed substantially in the last decade or so. The continued use of the 1979-1992 time period as the basis for extrapolation of baseline deforestation rates might undermine the project's credibility. This report has demonstrated the sensitivity of carbon savings to assumptions about baseline deforestation rates. FONAFIFO's nationwide data, not available when the OCIC and SGS were conducting their analyses, can serve as the basis for updating imputed baseline deforestation rates for the project.

As a first step, the revision of imputed baseline deforestation rates could be done in the simplest manner. A new linear extrapolation could be calculated using the FONAFIFO data. This paper reports the results of this calculation—the baseline deforestation rate drops from 0.85% to 0.38%. SGS recommends development of a more sophisticated, non-linear extrapolation method for predicting baseline deforestation. This would be of value, although even more useful would be the development of a behavioral-structural model of the type recommended by Chomitz (1998). Fortuitously, such a dynamic optimization model is currently being developed for Costa Rica (Kerr et al. 1999a, 1999b). The fact that commercial profit has been a major driver of Costa Rican deforestation in the past provides a theoretical justification for such a net profit maximization approach.

SGS's assessment of the first Tranche of carbon offsets indicates that about 40% of these (670,047 out of 1,688,434) should be held in a buffer to account for possible risks and uncertainties. SGS's continuous improvement approach and such a large buffer should create confidence in the carbon offsets claimed by the PAP. The 98% percent confidence intervals proposed by SGS for uncertainty about baseline deforestation rates seems too small. However, when viewed in the context of the overall size of the buffer, SGS's assessment does not seem unreasonable. Still, a somewhat greater contribution of offsets to the buffer to cover uncertainty about baseline deforestation rates might be useful, at least until more sophisticated modeling methods can be applied.

The PFP was established to mitigate the potential for the PAP to simply displace deforestation. The PFP calls for private landholders outside of protected areas to be paid to maintain or increase forest cover. The resumption of these environmental service payments, which were suspended in July of 1998, will be important. Whether land use requirements of the PFP are enforced and the current incentive structure (e.g. weak penalties, early payments) sufficient to discourage landowners from abandoning the program in the future, will determine whether the program effectively reduces deforestation on private land outside of Costa Rica's protected areas.

13.2. Lessons for GHG Accounting

This case study suggests a number of ways to increase confidence in estimates of forestry project GHG benefits. These fall into three categories:

(1) Ex-ante analysis: Give more attention to forecasting land cover, land use change. Review all available literature on drivers of land use change and, especially in the case of large projects where greater costs can be justified, utilize more rigorous analytic techniques to project baseline deforestation rates.

(2) Ex-post baseline evaluation: There exists a need for effective monitoring, evaluation, verification, reporting and certification to guard against overestimation of project benefits and to ensure benefits are realized on the ground;

(3) Leakage: The issue of leakage must be addressed to bolster the credibility of estimates of carbon benefits.

Constructing baselines for climate change projects presents technical and political challenges. Skeptics of AIJ and CDM type projects warn that they will inevitably lead to false claims of GHG emissions reductions. AIJ and CDM project developers face the burden of countering these claims despite the fact that no incontrovertible proof can be amassed to support their estimates of GHG benefits.

As the largest AIJ project to date in terms of carbon offsets produced, the PAP will be subject to extra scrutiny.[23] The need to construct baselines with skeptics in mind is particularly problematic for a country such as Costa Rica, which has made great strides in environmental protection. Indeed, it can be argued that recommending that the OCIC lower baseline deforestation rates for the PAP in order to reflect the slowing of deforestation in recent years in effect penalizes Costa Rica for the environmental progress the country has made. This is true in a sense. But the alternative, possibly exaggerated claims of environmental benefits, threatens the credibility of the PAP and perhaps the viability of the CDM as a means for encouraging global cooperation to combat climate change.

Ex-Ante Analysis

Baselines for most forestry projects generally give less attention to the task of predicting future deforestation than to the task of calculating the associated carbon impacts. More attention should be given to the predictive aspect, which is the greatest source of uncertainty. An important first step is the review of literature on deforestation trends, dynamics, and models of the country or region in question.

The type of modeling appropriate for baseline deforestation rates and patterns will depend on the type of project. Extrapolation is appropriate for small projects in areas where deforestation trends have been relatively stable. For larger projects, more costly and sophisticated behavioral-structural modeling is justified. The Appendix surveys the range of methods available for modeling deforestation and discusses their strengths and weaknesses. In different circumstances, different methods will be appropriate. There has been a boom in deforestation modeling in the 1990's (Kaimowitz and Angelsen 1998). Most of the models built have been economic, but in some cases decisions about land use do not revolve around profit maximization.

Baseline accuracy depends not only on methodology but also an appropriate institutional framework. Third party certification alone may not be the best guarantee of accuracy (Chomitz 1998). Not only project developers, but also firms offering certification services have incentives to bias upward estimates of a project's net impact. This report does not seek to impugn the motives of the OCIC or SGS. At the same time, this case study found that the project's baseline deforestation rates may be too high despite the participation of a third-party verifier.

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[23] See the UNFCCC web site for a list of AIJ projects (http://www.unfccc.de). The PAP is the largest on

Chomitz (1998) points to the experience of evaluating energy savings due to Demand-Side Management programs in the United States as instructive. Such programs face the same problem of constructing baselines to calculate benefits. Panels of public interest representatives have been used successfully to review the evaluations of third parties. Such an institutionalized public interest review process would be useful for the CDM as well.

Ex-Post Baseline Evaluation

This case study points to the importance of dynamic baselines and effective monitoring, evaluation, reporting, verification and certification. Deforestation rates and patterns change over time. Moreover, the sensitivity analyses conducted herein demonstrate the variability of carbon savings when different baseline deforestation rates are assumed. SGS's continuous improvement approach to certification offers an example of an operational framework for implementing dynamic baselines based on ex-post monitoring and evaluation. In adjusting the baseline over time, it will be important to try to discern and respond to long-term trends rather than short-term fluctuations.

Implementation of a project inherently changes reality on the ground. For the PAP, deforestation trends within the protected areas will not be useful for judging the accuracy of the ex-ante baseline scenario. However, if leakage can be accounted for, monitoring and evaluation of deforestation outside of the project areas can be used to assess the deforestation pressure that the protected areas would have been vulnerable to without the project. In a sense, this is a variation of the control plot strategy of ex-post evaluation.

Leakage

The question of leakage— indirect project effects —is important to the estimation of a project's net benefits and, ultimately, to the credibility of carbon offset estimates. Precisely calculating leakage quantitatively requires sophisticated statistical modeling that is data and computer intensive and pushes the limits of analytic expertise and data

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the list dated 13 October 1998.

availability. Another approach to addressing leakage is to identify the most troubling potential sources of negative leakage and then design parallel activities to address these.

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APPENDIX

Dynamics of Deforestation & Methods for Modeling Land Use Change

In order to construct baselines for forestry projects, some method must be chosen to project quantitatively how land use would have changed in the future without the project. This appendix examines the advantages and disadvantages of the different methods for modeling land use change. Normative models that explore the question of socially optimal land use are not covered. The Appendix starts with a discussion of the dynamics of deforestation. An understanding of the processes that lead to deforestation in a particular place is important to modeling the phenomena.

A.1. Dynamics of Deforestation

To model deforestation effectively, first it is necessary to understand the dynamics. What are the causes driving the processes that lead to deforestation? Since deforestation emerged as an international environmental issue in the 1970s and 1980s scientists have worked to identify its causes. The causes of deforestation will be unique in any particular place. Yet, some generalizations can be made about driving forces on a national or regional scale. For example, demand for pastureland to raise cattle was a key driver of deforestation in Central America in recent decades (Kaimowitz 1996). In contrast, conversion to pasture land plays a less important role in Southeast Asia, while demand-for-wood-driven logging has played a much larger role there than in Central America (Meyer and Turner 1994).

Brown and Pearce (1994) see in the empirical work on the causes of deforestation two fundamental driving forces: (1) the failure of international and national economic systems—as shaped by politics and policies—to reflect the true value of ecological systems; (2) competition between human and non-humans for limited remaining ecological niches, with population growth in developing countries intensifying the competition.

Kaimowitz and Angelsen (1998) contribute to our understanding of the dynamics of deforestation by looking at causes in a new way. They distinguish between immediate causes and underlying causes. The underlying causes operate at the macro-level. These include demographic change, government policies, technological change, and international and national market forces. Immediate causes of deforestation make up the decision framework within which potential agents of deforestation operate. These are referred to as "agents' decision parameters." The immediate causes or decision parameters include prices (output, input), available technology and information, risk, property regimes, restrictions on land use, and environmental characteristics (accessibility, soil quality, etc.).

In contrast to the analytically complex question of causes, it relatively easy to identify the small number of human activities that accounts for most deforestation. The literature refers to these human activities as pathways of change (Williams 1994), proximate causes of deforestation (Lambin 1994), or sources of deforestation (Kaimowitz and Angelsen 1998). The five main human activities responsible for deforestation in the tropics are (Turner and Meyer 1994):

1) <u>Agricultural Expansion</u> (includes commercial agriculture and farming due to spontaneous or government-organized migration)
2) <u>Pasture Expansion for Ranching</u> (a subcategory of agriculture)
3) <u>Logging</u>
4) <u>Fuelwood Collection</u> (for subsistence purposes)
5) <u>Infrastructure Development</u> (includes urban development, roads, and power plants)

A.2. A Comparative Survey of Methods for Modeling Deforestation

This discussion builds on Section 4.2., which outlined the elements of deforestation models. Methods are surveyed in greater detail, and the advantages and disadvantages of different methods are explored. No single methodological approach can accurately represent the complex processes affecting land use decisions (Lambin 1997). The best approach will depend upon the particular dynamics of the place being studied. The 1990s have seen a boom in development of econometric models (Kaimowitz and Angelsen 1998). Econometric models are based on the assumption that land use change occurs to maximize the monetary value of the land's output. For a country such as Costa Rica, where commercial profit has been a major driver of deforestation, econometric models are particularly well suited. However, in other cases, profit maximization will not be the objective that drives behavior. For example, in some cases forest clearance and cultivation may take place to demonstrate property rights.

In general, the methods listed below can utilize a range of mathematical forms: linear, logarithmic, logistic, quadratic, markov chain. Logistic growth and markov chain models, are listed as separate methods because they are particularly useful mathematical forms for modeling deforestation. They, as well as extrapolation and regression analysis, can also be components of the more complicated methodologies, such as system models. The advantages and disadvantages of each method are summarized in Table 9, below, and the discussion that follows, which includes examples.

Table 9.
Methods for Modeling Land Use Change: Advantages and Disadvantages

Method	Advantages	Disadvantages
Extrapolation	Simple and low cost. Can be accurate for areas where land use trends have been stable and are likely to remain so.	Land use trends are most likely to be stable for relatively small areas. Stability over long time periods is uncertain.
Multivariate Regression - including partial equilibrium econometric models	Valuable for empirically testing explanations of the ecological and socioeconomic driving forces underlying deforestation.	Like all models, regression based predictions assume unchanging functional relationships. Econometric models only appropriate where profit maximization is the objective of landowners.
Markov Chain	Probabilistic (stochastic) models are appropriate for modeling in presence of substantial uncertainty.	Probabilistic output cannot be used directly to establish baselines since offsets calculation must be deterministic to be specifically "measurable." Still, probabilistic results can be easily translated into deterministic type output.
Logistic Growth	Theoretical foundations exist for logistic growth models. Biological growth and human geographic expansion have been found to be logistic given resource constraints.	Most logistic growth models of deforestation have not been based on representation of underlying processes. While the theory is empirically based, the models have been analytically constructed.
Computable General Equilibrium	Allow more realistic representation of the complex market based, economy-wide interactions that may affect deforestation.	Deforestation may not be exclusively or mainly a market-driven phenomena. CGE models are relatively more costly and data intensive than some other methods.
Systems Models	Allows more accurate representation of complex subsystems with negative and positive feedback effects. More realistic ecological and cultural assumptions.	Relatively more complicated, data-intensive, and costly than some other methods.

Sources: E. Lambin (1994); Kaimowitz and Angelsen (1998).

Extrapolation

Extrapolation involves the projection of past deforestation trends into the future. The main advantage of this approach is that it obviates the need for an accurate representation of the main causative factors. The approach also offers simplicity. Only two points in time are needed to define a linear trend. More points in time can be used to discern and estimate non-linear trends. Any of the mathematical forms described above could be employed to fit a curve to the data, preferably with some theoretical basis.

This paper's Protected Areas Project case study illuminates a linear extrapolation technique. The average rate returned from analysis of the 1979 to 1992 data was used to define nine regional deforestation rates for the country. SGS's third party evaluation of the project led it to recommend development of a non-linear extrapolation based on the incorporation of additional data.

The GEOMOD2 Example. One quantitative approach not described among the mathematical forms above is in effect an extrapolation from a single year. Pontius and Hall (1994) develop a model called GEOMOD2 that projects future deforestation based on a cultivation index for each raster, or pixel of land. The cultivation index is a number that reflects the number of landscape variables that exceed a threshold level. The assumption underlying the model is that the agricultural frontier is the most important determinant of deforestation. Newly cultivated land and deforested land are assumed to be the same. Land use change patterns from forest to cultivated land are projected for the future by GEOMOD2 based on two categories of drivers and the principal of regional stratification:

1) Contiguity: new deforestation tends to occur near previous deforestation and new cultivation tends to occur near previous cultivation.
2) Geographic drivers: geographic characteristics of the land are also considered in determining a cultivation index for each raster. The geographic drivers included are: elevation, slope, soil type, proximity to cities, proximity to rivers, precipitation, temperature, cloud cover and "aspect" (slope). The model does not consider distance to the nearest road, which would seem to be a weakness. Proximity to cities and rivers and slope may account for accessibility to some extent.
3) Regional stratification: The model can take into account different deforestation patterns among regions (due to government policy, demographic dynamics, etc.) by stratification: the model determines different patterns of land use change for different regions.

The authors note that their model requires a number of assumptions, most importantly: (1) association indicates causation; and (2) cultivation patterns will remain essentially constant.

They note that multiple regression could be used to derive equations for the probability of deforestation based on the information included in the geographic data set

Costa Rica was chosen to test the performance of GEOMOD2 because of the availability of complete data from two points in time. Data sets for two years—1940 and 1983—were used. Two tests were run. Either of the years served as a basis for projection (either forward or backward), the other was used to judge accuracy. In the case of Costa Rica, GEOMOD2 was modified to incorporate six geographic drivers: Soil Type, Potential Land Use, Lifezone, Soil Moisture, Rainfall and Elevation. Again a key driver was contiguity (recognizing that new deforestation often occurs where it has just happened). The model was relatively accurate in its projections. Using the 1940 data, GEOMOD2 was run forward for 43 years. Comparing the projected deforestation with the actual 1983 data showed that the model predicted 84% of the rasters (pixels of land) correctly. Then, using the 1983 data, GEOMOD2 was run backwards in time to 1940. The model predicted 74% of the rasters correctly in this second case.

Regression Analysis

Regression analysis is an oft-used empirical method for specifying functional relationships. If successful, regression analysis creates a functional form whereby the variance in a dependent variable can be explained by the variance in independent, or explanatory, variables. Various functional relationships—linear, quadratic, logistic, and probabilistic (dichotomous)—can be defined. Multivariate regression models with econometric theoretical foundations have become a commonly used method in evaluating deforestation since Panayotou and Sungsuwan (1989) published their seminal work on deforestation in Northeast Thailand. Such models offer the ability to empirically test theories on the ecological and socio-economic causes of deforestation. Data limitations can be a problem, as they can be for all empirical methods. Brown and Pearce's *The Causes of Tropical Deforestation* (1994) provides numerous examples of econometric models. Three examples are discussed below.

A simple univariate regression model for Southern Cameroon. Mertens and Lambin (1997) develop an empirical model that predicts land use change in Southern Cameroon based on four landscape variables and remote sensing data. In order to quantify the relationship between their chosen landscape variables and land use change, the authors estimate a series of univariate least-square regression models with the frequency of deforestation as the dependent variable and the following independent variables:

1) proximity to roads
2) town proximity
3) proximity to a forest/non-forest edge
4) forest-cover fragmentation

Landsat data from 1973 and 1986 provides information on land cover for the region under consideration in southern Cameroon. Digital maps of road networks and town were produced by manual digitization and included in the data set. Population and crop production data were also compiled, but their level of spatial aggregation was too coarse to be incorporated. Different mathematical functions (linear, logarithmic and quadratic) were used to estimate the relationship between deforestation and the four explanatory variables. For the dependent variable, area deforested, the following relationships were found:

1) *road proximity*: the relationship was found to be a negative logarithmic function, with the frequency of deforestation decreasing rapidly with increased distance from roads.
2) *town proximity*: the modeling task was complicated by the fact there forests have already been cleared in the areas immediately surrounding towns. Deforestation increases sharply over the 3-10km range and then decreases. This relationship is estimated using a quadratic function.
3) *proximity to forest/non-forest edge*: another negative logarithmic function was found to best approximate the relationship. There is a much greater occurrence of deforestation near the forest/non-forest edge, e.g. near places where deforestation has already occurred.
4) *forest-cover fragmentation*: only a weak linear relationship was apparent; the variable was not included in projecting future deforestation.

A threshold of 80% deforestation for landscape variable values was used to identify those areas likely to be subject to deforestation. In other words, if at least 80% of the land that exhibits a particular independent variable value has been cleared, then a parcel of land was considered at risk with regard to that landscape variable. Each parcel of land's risk of deforestation was determined by how many times it crosses over the risk threshold for each of the three spatial variables. The final output of the model is a map that identifies four deforestation risk zones: zero, low, medium and high risk. An area was at high risk if all three independent variables listed above indicate that the area was at risk. If two of its landscape (e.g. independent) variables indicate a risk of deforestation, the area was labeled medium risk. One or no landscape variables over the threshold indicated low and no risk respectively. Lambin and Mertens note that their risk projections were based completely on landscape variables, thus ignoring socioeconomic factors. However, they predict that if deforestation patterns and rates remain relatively unchanged in the future, then the areas they identify as high risk would be completely deforested within 26 years.

<u>*An econometric model of Northeast Thailand.*</u> In a seminal work that preceded the boom in econometric modeling, Panayotou and Sungsuwan (1994) develop an econometric model to test theories on the causes of deforestation in Northeast Thailand.[24] The authors posit a deforestation function with a theoretical foundation of three demand functions: derived demand for agricultural land; demand for timber, and; demand for fuelwood. They develop a co-variance model using ordinary least squares with dummy variables to allow the intercept term to vary over time and cross section units. At first, a translog function was specified to allow for interaction between explanatory variables. However, the interaction terms in the translog function were not statistically significant, so they were dropped and, in its final form, the deforestation function collapsed to a log linear regression model.

[24] The citation for 1994 refers to presentation of the model in Chapter 13 of Pearce and Turner's *The Causes of Deforestation.* Panayotou and Sungsuwan first presented their model in a Harvard Institute for International Development (HIID) Discussion Paper. The HIID paper is also cited in the list of references (Panayotou and Sungsuwan 1989).

The model includes socioeconomic data and spatial landscape characteristics such as road density and distance from markets in Bangkok. The geographic data was gathered from remote sensing surveys conducted in 1973, 1976, 1978 and 1982. Inadequacy of this data for estimating a time series equation led the authors to pool cross-section data over time to secure sufficient degrees of freedom and efficient parameter estimates. The study found four variables to be significant at the 0.01 level: wood price, income level, population density and remoteness (distance from Bangkok). A positive relationship exists for the first three of these and deforestation decreases with increasing remoteness (an inverse relationship).

Another Econometric Model of Thailand. Another multivariate regression econometric model similar to one estimated by Panayotou and Sungsuwan re-examined the relative importance population, road building and geophysical variables in determining deforestation in Thailand (Cropper et al. 1997). The model takes into account aspects like soil quality and slope on a provincial scale. The model is based on the assumption that the amount of forested land cleared reflects equilibrium in the market for cleared land. The supply side of the market depends on the cost of clearing land and the profitability of agricultural production (in turn reflecting, labor and transportation costs). The demand side of the market is influence by population size. Operationally, the model consists of three jointly-determined functions: (1) the market for cleared land; (2) the agricultural household function; (3) the road function, specifying road building based on the demand for transportation and costs of road construction.

The model is estimated using data from five years over the time period 1976-1989. The authors experimented with a variety of functional forms, but ultimately settle on a linear probability model estimated using Two-Stage Least Squares. The model's results show that increases in the number of agricultural households (population) and road density increase the percentage of forest cleared in each province cleared. The effects are smaller than those found by Panayotou and Sungsuwan, but there is some regional variation. Population has a larger impact in the northern provinces and road density has a larger impact in the south. The model also shows that steep slopes and poor soil quality provided some protection against deforestation, again with regional variation.

A Multivariate Regression Model for the Brazilian Amazon. Alex Pfaff (1995, 1999) has developed an econometric land-use model for the Brazilian Amazon to explore the effects of a number of potential driving forces of deforestation in that region. The assumption underlying the model is that land is allocated to maximize its expected total return (both immediate and discounted future returns). The observations used in the regressions are at the municipio, or county, level. A spatial element is introduced, as the factors describing a given county include conditions in neighboring counties. The dependent variable is derived from remote sensing data on forest cover. The years used in the regressions are 1978 and 1988. The regressions analyze the effects on forest cover of a number of natural and socioeconomic factors. The specific independent variables included are: road density, river density (like roads, a transportation/access variable), distance to national and state capitals (a transportation/costs variable), population density, density of development projects, density of Banco de Brasil branches, average industrial wage, percentage of land in cerrado (thought to be easier to clear and use than primary forest), and a soil-quality measure based on nitrogen content.

Dr. Pfaff finds that both increased density of paved roads in a given county, as well as increased density of paved roads in neighboring counties, leads to greater deforestation in that given county. Unpaved roads, though, did not have a significant effect. Development projects were also found to significantly increase deforestation in the pooled results, although in the cross-sectional regressions they have a significant effect for 1978 but not for 1988. As expected, greater distance from major markets in the rest of the country discourages deforestation, while better soil quality encourages deforestation. On the ever-controversial question of population, Dr. Pfaff finds that while the simple level of population does not have a significant effect once the other potential driving forces are also included in the regressions, a significant effect of a greater population is found when the marginal impact of additional people is allowed to depend on the number of people already in an area. In particular, the first arrivals to an area are found to have a substantially greater impact than later arrivals. This result implies that the spatial distribution of a given population affects its impact on forest cover. The more concentrated the people, the lower their impact on the forest.

Computable General Equilibrium Models

Computable General Equilibrium (CGE) Models represent mathematically the interaction of many markets—markets for goods and services, markets for factors of production and financial markets—which determines how macroeconomic equilibrium is reached, and thus what direction the economy will take. A CGE model has been developed for Costa Rica (Persson and Munasinghe 1997). The model uses two submodels— representing the logging sector and clearing of land by squatters— that interact with other economic sectors in order to determine the amount deforestation. Like systems models, CGE models can more realistically represent the dynamic, interactive processes that cause deforestation. In particular, the CGE approach offers the chance to consider the economic and environmental impacts of macroeconomic policies. One disadvantage of the method is its focus on markets. In some places, the causes of deforestation will not be exclusively or mainly a market-driven phenomenon.

Markov Chain Models

The Markov chain approach to modeling deforestation is already widely used in ecology to model landscape successions and in geography to model the diffusion of landscape characteristics. As a stochastic, i.e. probabilistic, approach, the Markov-chain method is particularly appropriate for modeling in the presence of substantial uncertainty in which case reaching specific deterministic conclusions is less justifiable. A Markov model of deforestation is based on the construction of a transition matrix that predicts the probability of land use change. The probabilities of transition to a different type of land use or land cover could be determined via a variety of statistical techniques, most Markov deforestation models simply use the percentage change from one time period to the next. Such models rely on the unrealistic assumption that deforestation is essentially a two-stage process when in fact multiple stages occur.

Logistic Growth Models

Research in biology and ecology has demonstrated the existence of relationships that can be approximated by logistic functions. Logistic functions, which define s-shaped curves, can effectively represent processes that increase slowly at first, then rapidly, followed by a slowdown. In particular, growth in resource-constrained environments has been shown to be logistic in many cases (Lambin 1994). The process of deforestation may exhibit such a pattern in some cases. Over the long run, deforestation is at first very slow, increases rapidly (as population and technology spread human influence) and then slows down again after the most accessible and highest quality land has been cleared. The parameters of logistic models can be empirically or analytically estimated.

Example of a generic logistic model. Grainger (1990) develops a simple logistic model that could be applied anywhere agricultural expansion is the main driver of deforestation. Like the GEOMOD2 model discussed above, the assumption is that the area of deforested land will equal the area of newly cultivated agricultural land. The key causal drivers in the model are annual growth rates of population, per capita food consumption and yield per hectare of land. These are projected into the future and used as inputs to the model.

System Models

A systems model creates a mathematical representation of several interacting processes. A "whole system" approach offers the chance to incorporate the complex positive and negative feedbacks that can determine the direction taken by interacting ecological and social systems. Many mathematical functions can be included in the various subsystems that comprise the model as a whole. Further, the parameters of the functions can be either empirically or analytically based. The ecological and cultural assumptions that systems models use are more realistic than some other methods, but their statistical performance has not yet proven effective (Lambin 1994). The method is particularly computer intensive.

Lambin (1994) recommends a systems approach as the most capable framework for successfully integrating the spatial, temporal, and causal dimensions in a land use/land cover change model. Lambin develops the outline of a hybrid model that—like the DELTA model described below— revolves around a Markov chain-based stochastic core linked to deterministic submodels. The submodels are based on a spatial stratification of the processes underlying deforestation, e.g. an economic model of land rent is suggested for frontier areas and a model of agricultural colonization is suggested for roadside areas. Ultimately, Lambin warns that the cost of a more realistic and complex approach is a less readily operational model.

The DELTA Model. The creators of DELTA (Dynamic Ecological - Land Tenure Analysis) classify their model as a stochastic, dynamic microsimulation model (Dale et al. 1993; Dale et al. 1994; Southworth et al. 1991). DELTA's stochastic core integrates three deterministic socioeconomic and ecological submodels. The sub-models simulate settlement diffusion, land-use change, and carbon release. DELTA was created to contrast potential land management approaches in the Brazillian Amazonian region of Rondonia, but the approach can be used generally to project land use change and carbon release where parcels of land for settlers are laid out along transportation routes.

Land-use change parameters are inputs to DELTA. The assumption is that these patterns can be roughly estimated from observation. Land use decision parameters include: proportion of lot area to be cleared each year, conditions for coalescing lots into pastures, criteria for changing tenants mix of land uses, and conditions under which colonists move to a new lot. For Rondonia, the mix of land uses on a particular lot is assumed to be some combination of annually cropped land, perennially cropped land, animal grazing, fallow and undeveloped forest.

DELTA is based on a spatially explicit database that was created by digitizing maps using the ARC/INFO geographic information system. The maps provide information on:

lifezone type, transportation networks, pasture and agricultural suitability. The model's output is a probabilistic assessment for each parcel of land that enables the comparison of the amount of forest clearing predicted under different methods of land management. DELTA shows that sustainable land management practices rather than traditional land management practices would drastically reduce deforestation and carbon emissions in Rondonia.